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CALCULATED HEAT TRANSFER AND COOLING SYSTEM PERFORMANCE, VOLUME I

XV-5A

LIFT FAN FLIGHT RESEARCH AIRCRAFT PROGRAM

CONTRACT NUMBER DA44-177-TC-715

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CALCULATED HEAT TRANSFER AND COOLING SYSTEM PERFORMANCE

Volume I

XV-5A LIFT FAN
FLIGHT RESEARCH AIRCRAFT PROGRAM
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GENERAL ELECTRIC COMPANY
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Prepared by W. B. Davis
for B. W. Ela, Jr.
Technical Specialist
Thermodynamics

Prepared by C G Branson
C. G. Branson
Thermodynamics Engineer

Approved by W. B. Davis
W. B. Davis, Group Engineer
Technical Sciences, XV-5A Program

Approved by H B Starkey
H. B. Starkey
Sr. Project Engineer
XV-5A Program

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1.0 SUMMARY

The two volumes of this report present calculated cooling and structural protection system performance characteristics of the U.S. Army XV-5A Lift Fan Research Aircraft in terms of its estimated and experimentally determined induced environment; in terms of its structural, component, and operational requirements; and in terms of ARDC standard and ANA Bulletin 421 Hot Day conditions. This is Volume I.

The XV-5A, is a two-place V/STOL aircraft capable of flight at high subsonic Mach numbers. The aircraft was designed and built by the Ryan Aeronautical Company under contract to the General Electric Company for research flight testing of the G.E. Lift Fan Propulsion System. Based on analysis and limited test data, the aircraft cooling and structural protection systems are believed to have sufficient performance capability to permit orderly conduct of Installed System Functional, NASA-Ames 40' x 80' Wind Tunnel, and Edwards Air Force Base Flight Test Programs even though externally induced environmental temperatures to 1040° F develop during fan mode operation.

Occasional local and minor overheating problems are expected within the broad range of possible operating conditions; however, it is expected they can be overcome with minor structural modifications, installation of additional insulation, and/or minor modification of operational procedures.

Lack of detailed knowledge of the externally induced environment made cooling and structural systems designs and analysis difficult, leading at times to results which may prove too conservative, and at other times, too optimistic. In an attempt to gain further insight to this complex problem, a procedure was developed whereby existing literature data on downwash phenomena could be applied quantitatively to the XV-5A induced environment. While more fundamental and experimental data are needed before important aspects of the induced environment can be investigated further, results obtained to date are encouraging. Results show directional effects of aircraft control settings, and indicate the strong possibility of hot gas ingestion by the engine and cooling system air inlet. Perhaps most important of all, these results indicate means whereby adverse effects may be minimized or eliminated.

A comprehensive survey of the XV-5A induced environment is recommended, including temperature and velocity measurements for the full range of aircraft operating conditions, including altitude, power setting, control settings and local ground wind velocities.

2.0 INTRODUCTION

This report consisting of two volumes, presents calculated heat transfer and cooling system performance for the U.S. Army XV-5A Lift Fan Research Aircraft. The XV-5A aircraft, a two-place V/STOL aircraft capable of high subsonic flight, was designed and fabricated by Ryan Aeronautical Company to evaluate the General Electric lift fan system. The XV-5A propulsion system consists of two G.E. X353-5B propulsion systems including lift fans, diverter valves and modified J-85-5B gas generators, two sets of lift fan inlet closure doors, one G.E. X356 pitch (nose installation) fan, a set of two pitch fan thrust reverser doors and pitch fan inlet louvers, two exhaust ducts and nozzles, two thrust spoilers, and associated power distribution ducting and controls. The interrelation of these components and the aircraft are shown in Figure 2.1 and 2.2.

The XV-5A aircraft internal structure is fabricated principally of aluminum alloys, except for a few local areas subject to intensive heating ranges. The fuselage skin is constructed of a number of metals including aluminum, titanium, magnesium-thorium, and steel alloys as shown in Figure 2.3. Local skin areas exposed to severe heating for extended periods during aircraft testing have been protected by external insulation and are also shown in Figure 2.3. Figure 2.4 shows the nose and two-position main landing gear systems. Protection of main landing gear components, although under study at the time of rollout, is not considered in this report.

The XV-5A aircraft may be operated in either conventional (turbojet) mode or lift fan mode by selecting diverter valve position. In the conventional mode, the fan inlet and outlet doors and vanes are in the closed position to give an aerodynamically clean configuration; in the lift fan mode, fan inlets and outlets are open.

During V/STOL operations involving lift-off, hovering and forward flight, the fan streams are modulated for trimmed flight with generally symmetrical flow fields; however, aircraft pitch, roll and yaw control applications cause transient, differential, fan-stream modulations which produce transient asymmetrical external (induced) flow fields, particularly in

proximity to the ground. Forward thrust is obtained by vectoring the wing fan streams aft by use of exit louvers.

In the fan mode, hot gases from the modified J85-5 gas generator (to 1250° F) are diverted to the fan tip turbines and then exhausted downward from the inboard quadrants of the wing fans and the aft quadrants of the nose fan. As a result of these hot turbine exhaust gases (to 1040° F), the aircraft becomes exposed to and enveloped, to varying degrees, in locally induced environments which differ substantially from prevailing ambient conditions. Located within these induced environments, the various aircraft and propulsion system components are affected by the local flow fields, particularly their detailed temperature and velocity distributions.

Testing and operation considered in design of the aircraft include static ground tests, NASA-Ames 40' x 80' wind tunnel tests, flight tests at Edwards Air Force Base, pilot training and familiarization, exploration and extension of aircraft operating envelope, handling qualities, etc., and normal operations. Against this background, the calculated heat transfer and cooling system performance of this report is developed. Results are applicable to the aircraft configuration at the time of rollout, and do not reflect changes or modifications resulting from ground and flight tests.

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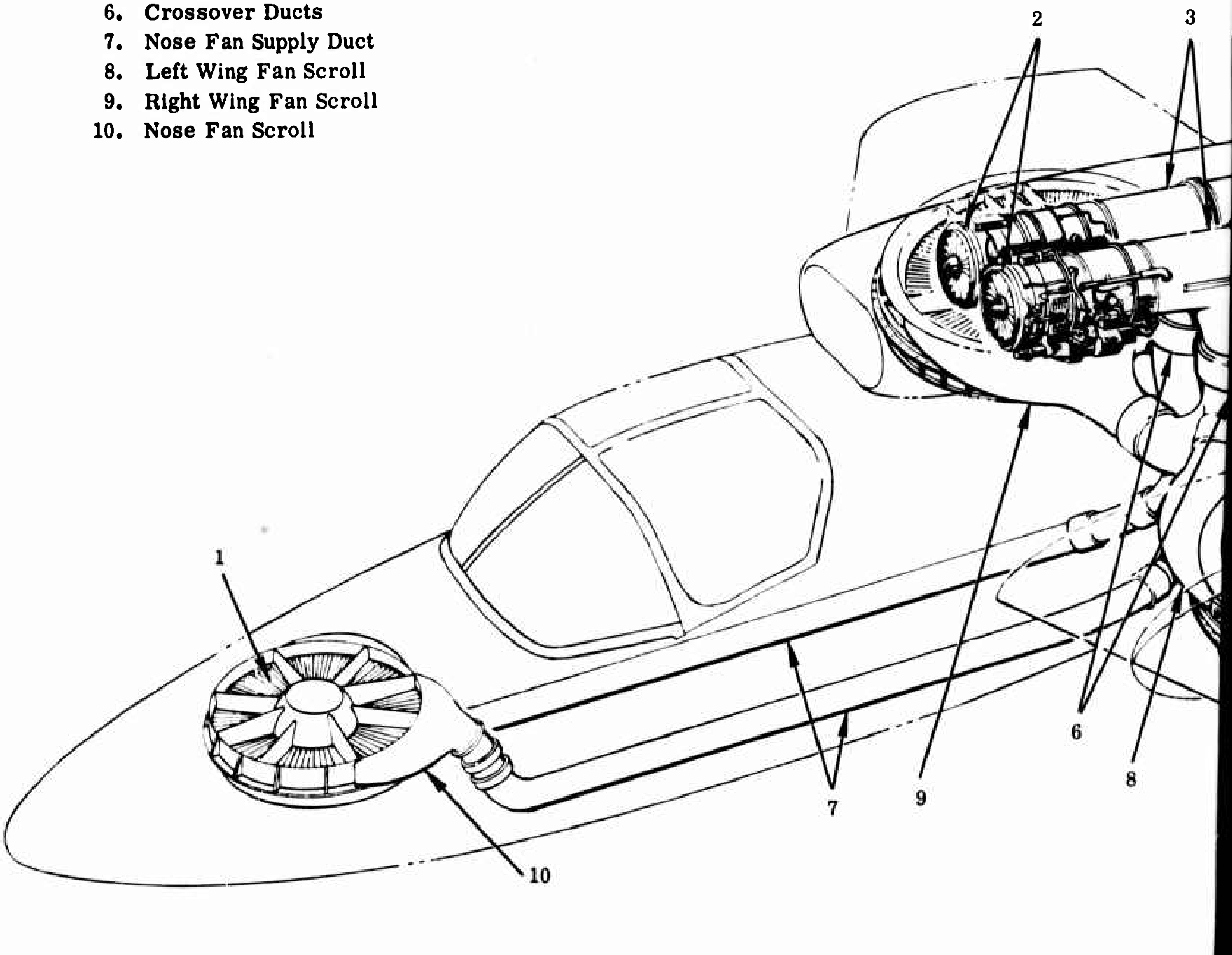
1. Nose Fan
2. Gas Generator
3. Diverter Valve
4. Engine Tail Pipe
5. Wing Fan
6. Crossover Ducts
7. Nose Fan Supply Duct
8. Left Wing Fan Scroll
9. Right Wing Fan Scroll
10. Nose Fan Scroll



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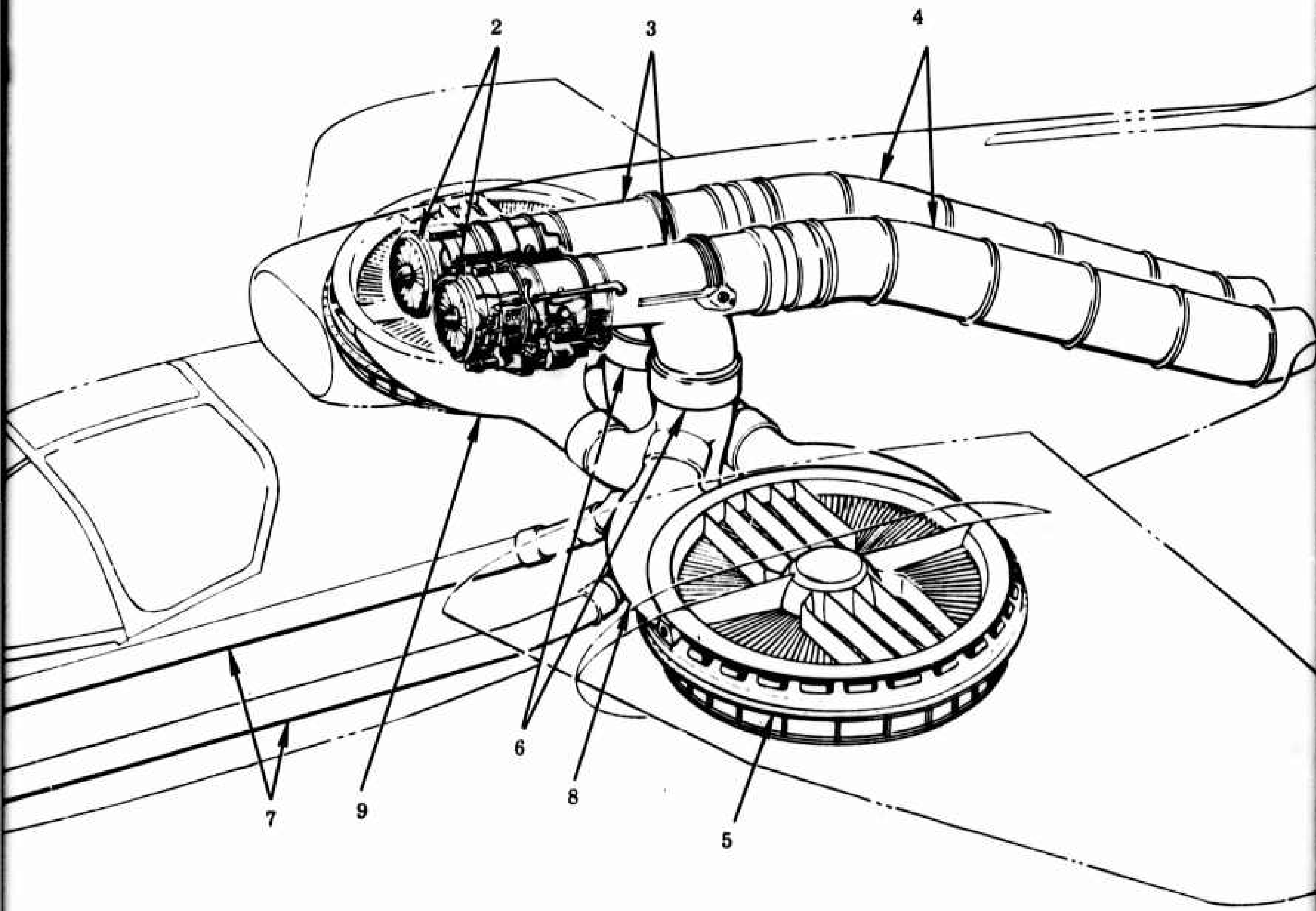
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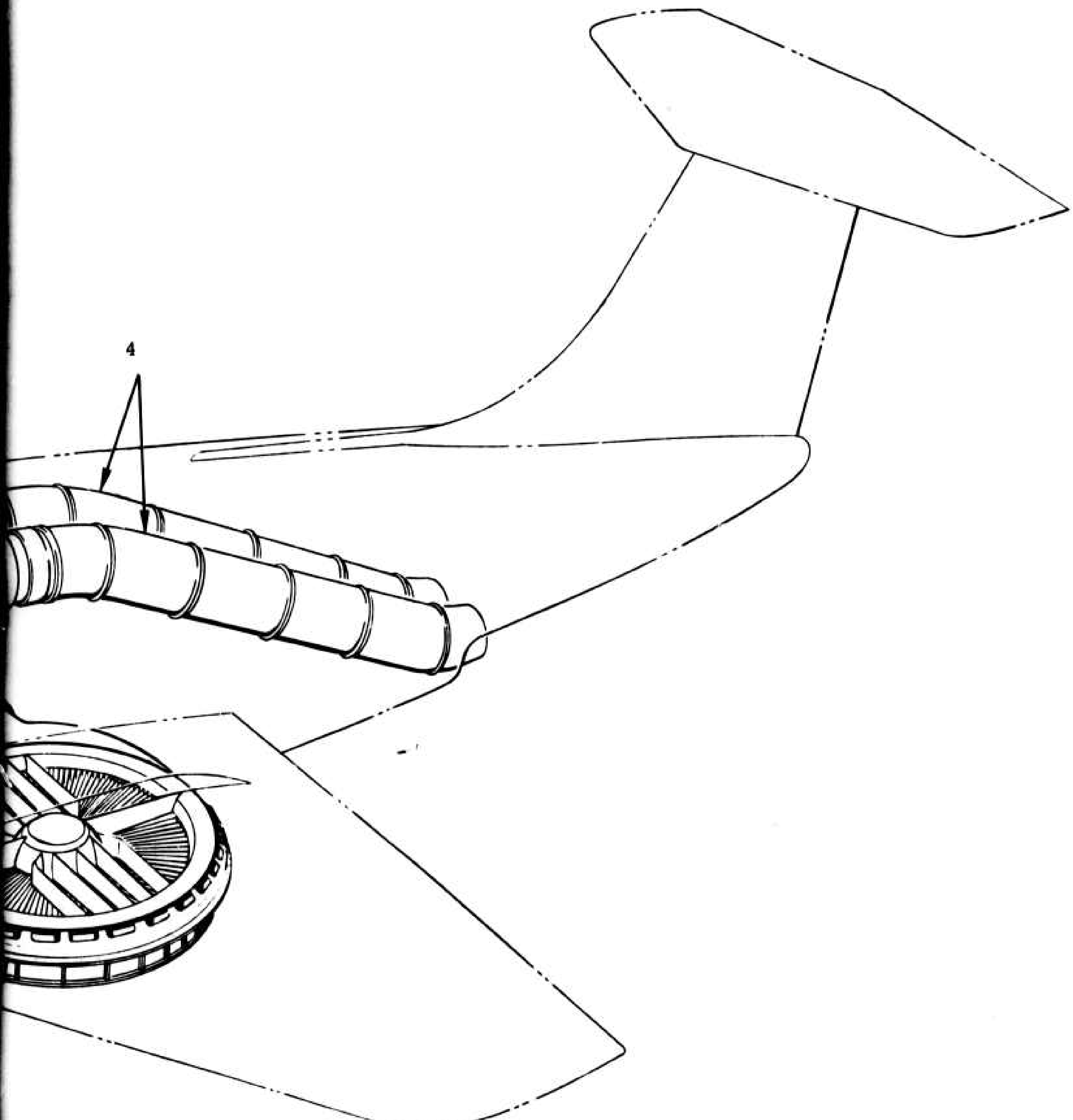
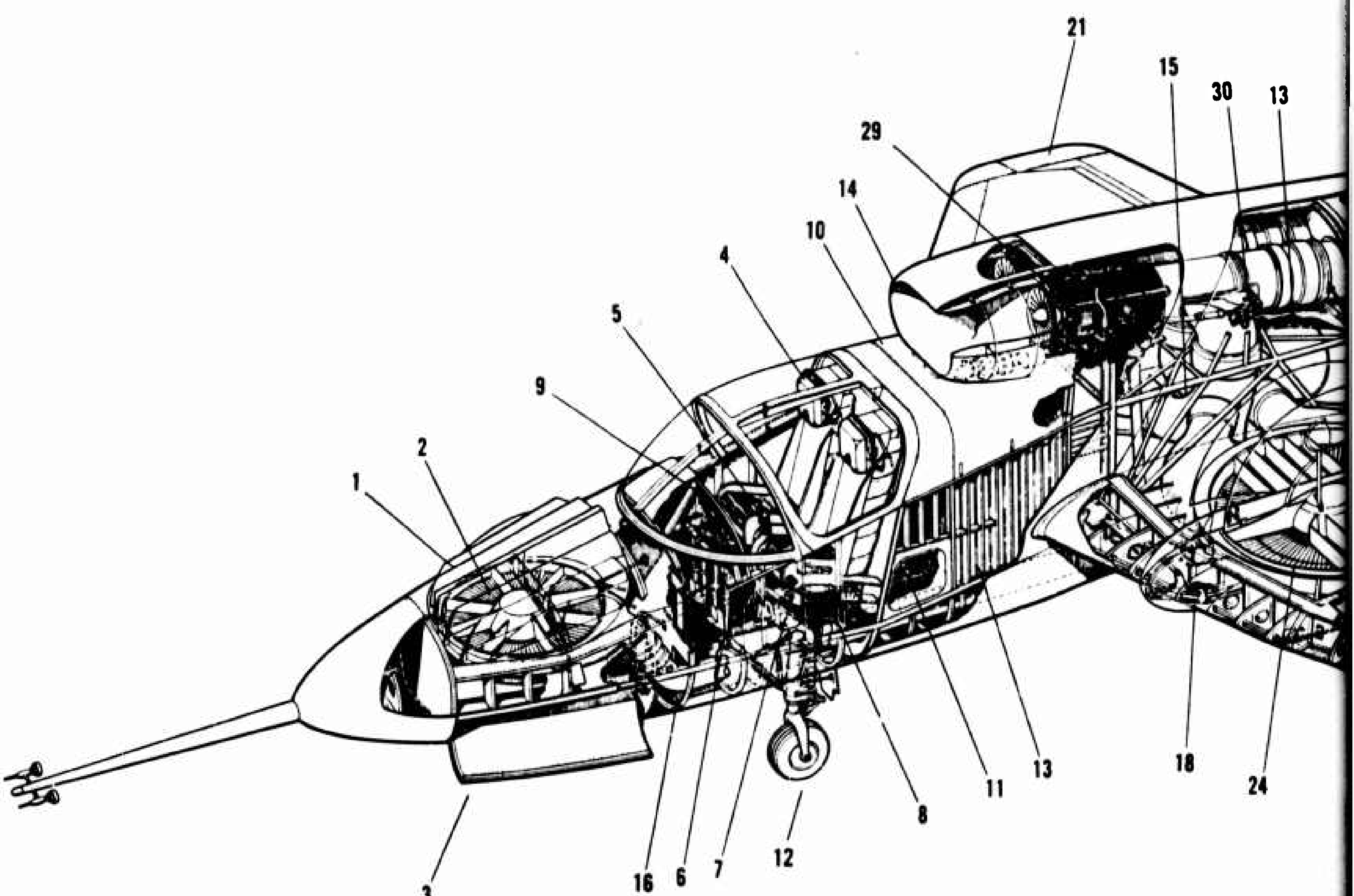


Figure 2.1 Propulsion System



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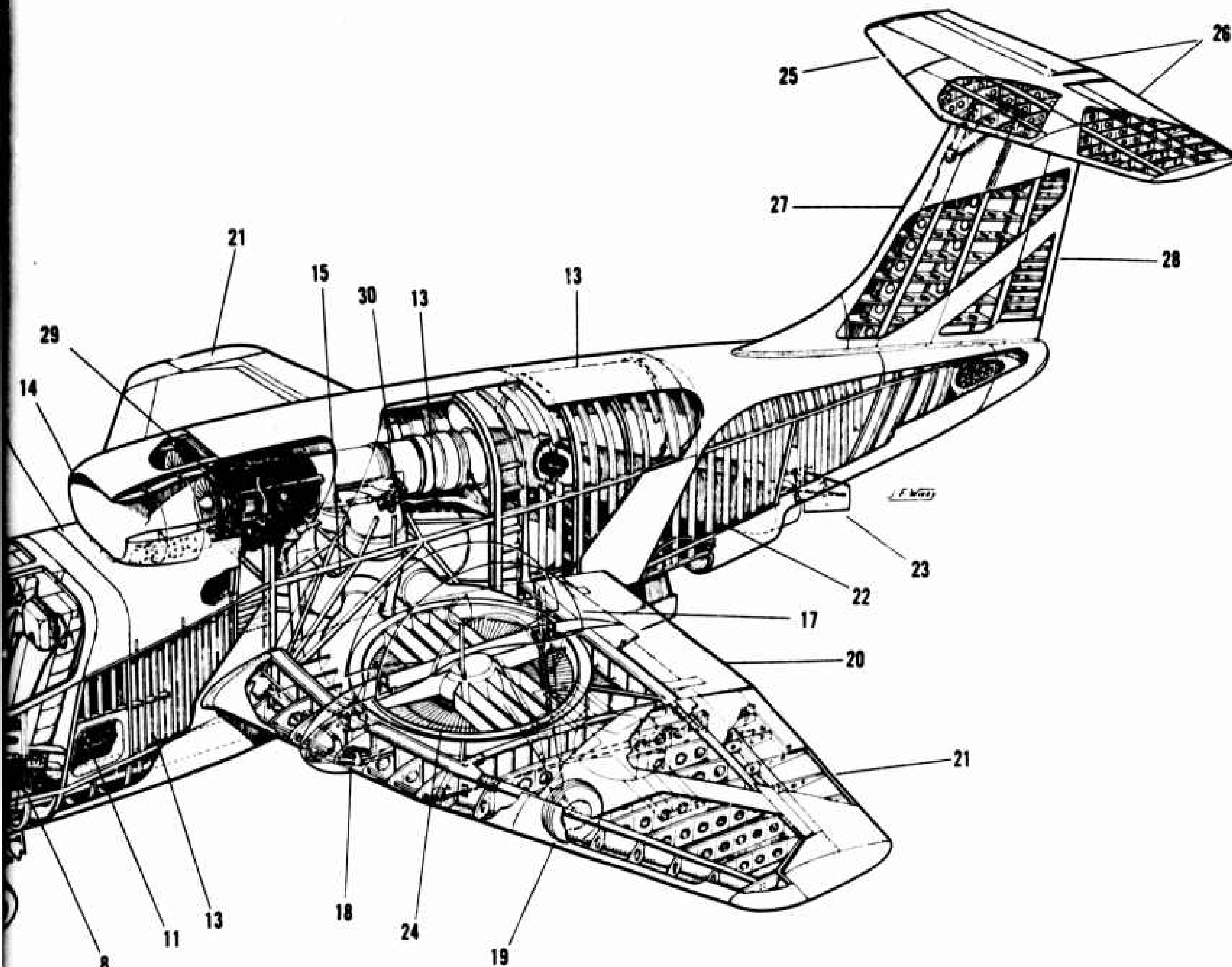
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Figure 2.2

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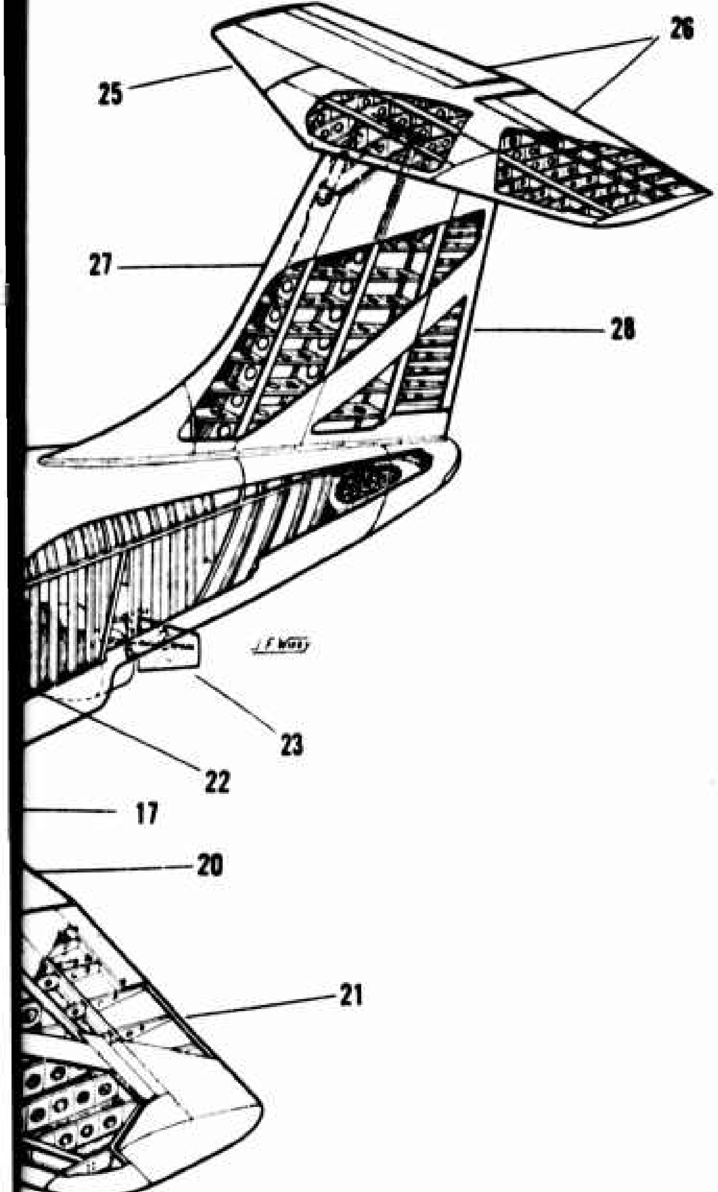

1. NOSE FAN INLET LOUVERS
2. GE-X376 PITCH CONTROL FAN
3. NOSE FAN THRUST REVERSERS AND NOSE FAIRINGS
4. ZERO-ZERO EJECTION SEAT
5. CONVENTIONAL CONTROL STICK
6. RUDDER PEDALS
7. THROTTLES
8. LIFT CONTROL STICK
9. INSTRUMENT PANEL
10. HYDRAULIC COMPARTMENT

11. ELECTRICAL COMPARTMENT
12. NOSE GEAR
13. FUEL TANK
14. SINGLE SPLIT INTAKE
15. CROSSOVER DUCT
16. NOSE FAN SUPPLY DUCT
17. MAIN FAN CLOSURE
18. EXIT LOUVER ACTUATORS
19. TWO POSITION LANDING GEAR
20. FLAP

21. AILERON
22. ENGINE TAIL PIPES
23. THRUST SPOILERS
24. GE-X353-5 LIFT FAN
25. FULL MOVEABLE HORIZONTAL STABILIZER
26. ELEVATORS
27. VERTICAL FIN
28. RUDDER
29. GE J85 GAS GENERATOR
30. DIVERTER VALVE

Figure 2.2 XV-5A Aircraft General Arrangement

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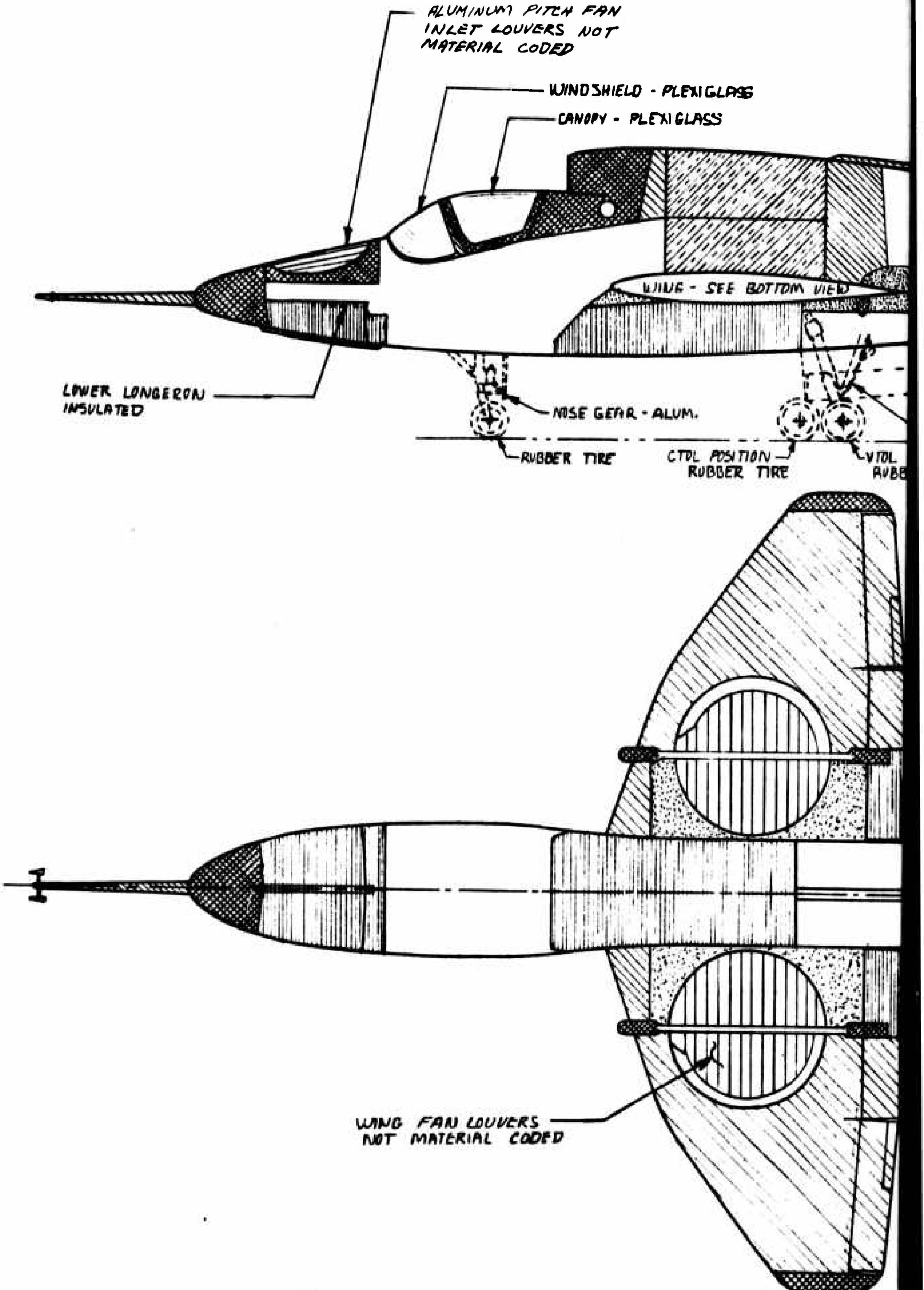
ALUMINUM PITCH FAN INLET LOUVERS NOT MATERIAL CODED
WINDSHIELD - PLEXIGLASS
CANOPY - PLEXIGLASS
WING - SEE BOTTOM VIEW
LOWER LONGERON INSULATED
NOSE GEAR - ALUM.
RUBBER TIRE
CTOL POSITION RUBBER TIRE
WING FAN LOUVERS NOT MATERIAL CODED

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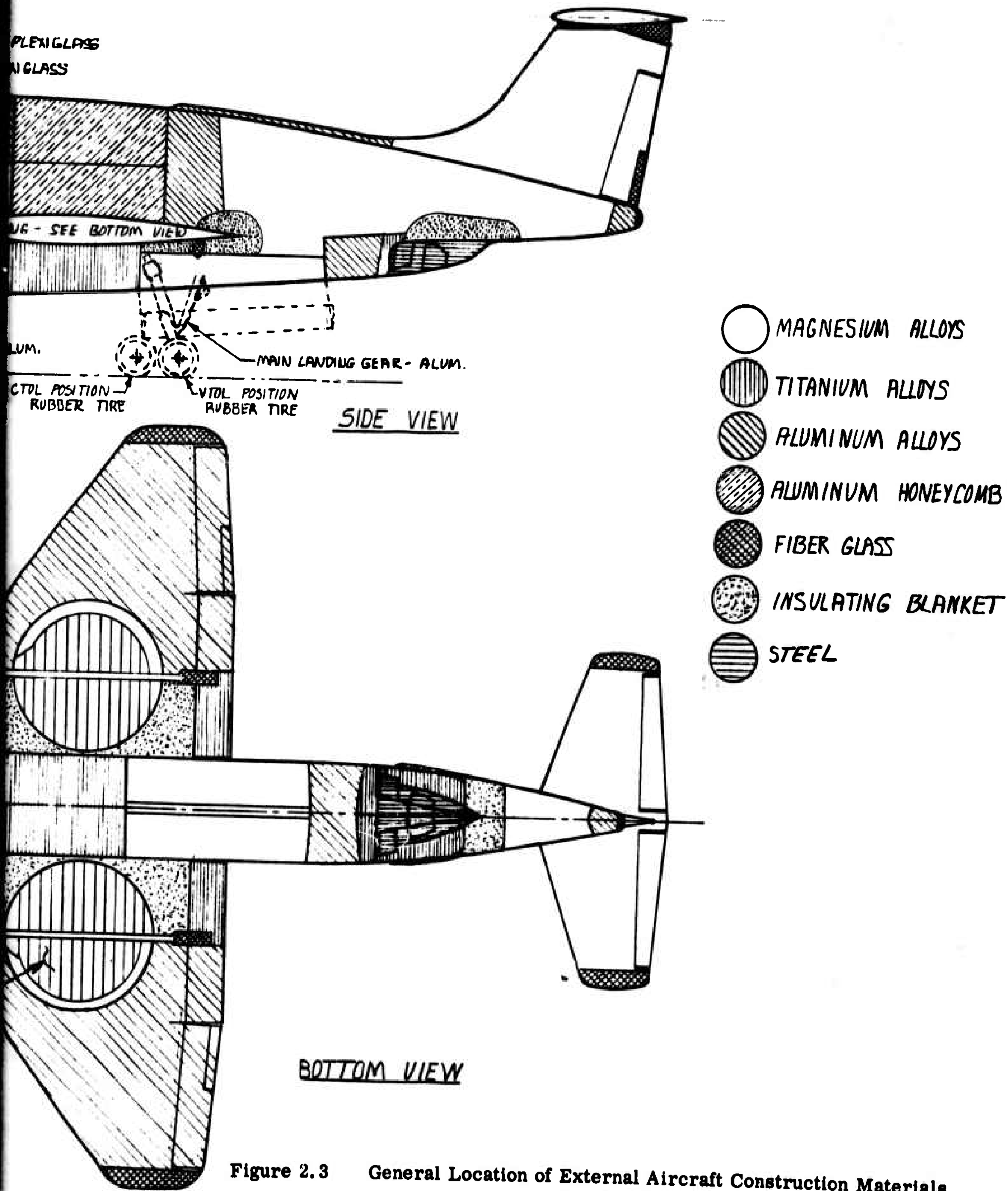
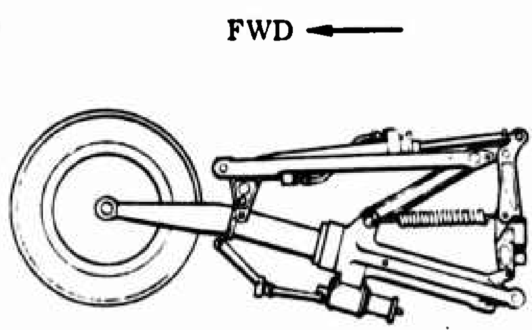


Figure 2.3 General Location of External Aircraft Construction Materials

B

NOSE LANDING GEAR

1. NLG HYDRAULIC ACTUATOR
2. NLG LOCKED SWITCH
3. JURY BRACE
4. SPRING
5. SHOCK STRUT
6. NLG WHEEL ASSEMBLY
7. SHIMMY DAMPER
8. GROUND LOCK PIN
9. TORQUE LINKS
10. UPPER DRAG BRACE
11. LOWER DRAG BRACE



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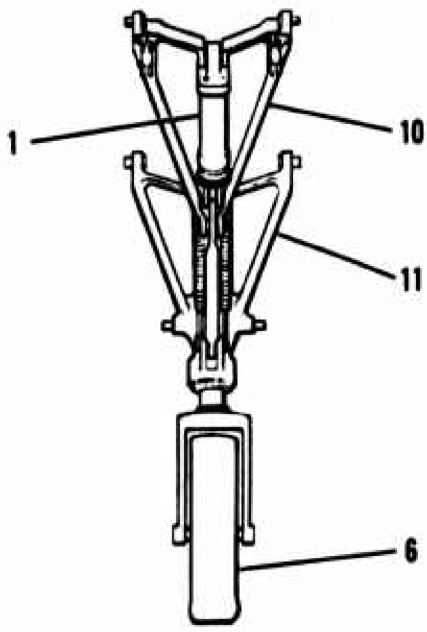
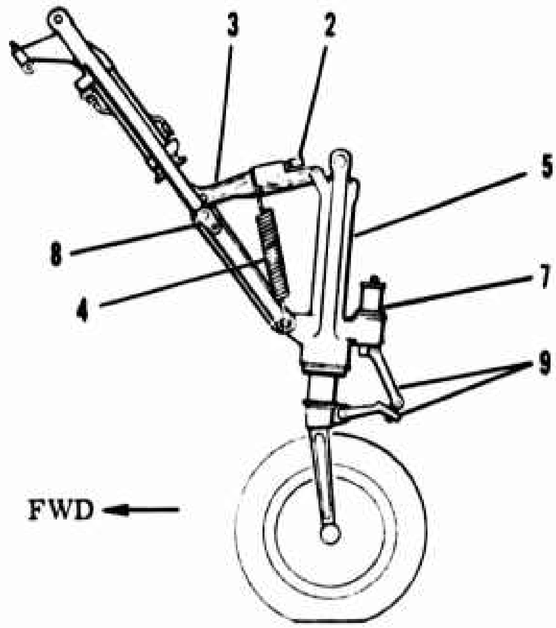
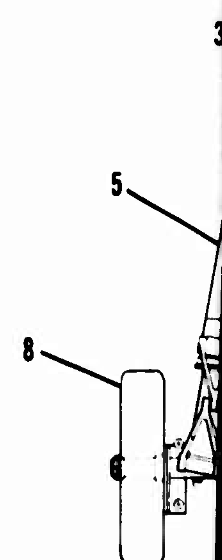


FRONT VIEW



SIDE VIEW



NOSE LANDING GEAR

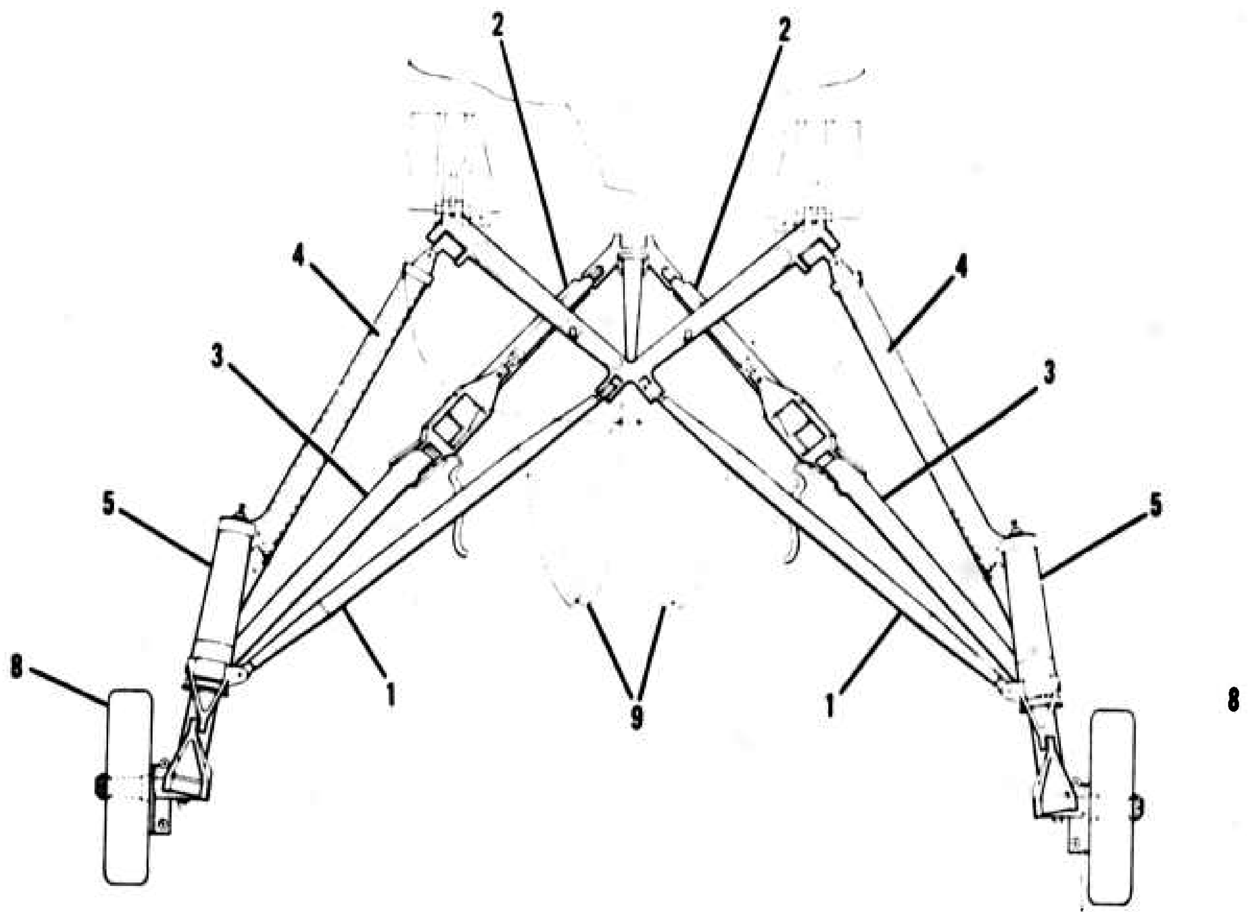
A

LANDING GEAR

YDRAULIC ACTUATOR
OCKED SWITCH
BRACE
G
STRUT
HEEL ASSEMBLY
Y DAMPER
D LOCK PIN
E LINKS
DRAG BRACE
DRAG BRACE

MAIN LANDING GEAR

1. SIDE SWAY BRACE
2. MLG HYDRAULIC ACTUATOR
3. DRAG STRUT ASSEMBLY
4. EMERGENCY PNEUMATIC SYSTEM RESERVOIR
5. SHOCK STRUT
6. TORQUE LINK
7. MLG FOLD MECHANISM
8. MLG WHEEL AND BRAKE ASSEM
9. DOORS (SHOWN IN "OPEN" POSI
10. DOOR MECHANISM
11. UPLATCH
12. 2-POSITION MECHANISM (MODE



FRONT VIEW

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Figure 2.4

B

MAIN LANDING GEAR

1. SIDE SWAY BRACE
2. MLG HYDRAULIC ACTUATOR
3. DRAG STRUT ASSEMBLY
4. EMERGENCY PNEUMATIC SYSTEM RESERVOIR
5. SHOCK STRUT
6. TORQUE LINK
7. MLG FOLD MECHANISM
8. MLG WHEEL AND BRAKE ASSEMBLY
9. DOORS (SHOWN IN "OPEN" POSITION)
10. DOOR MECHANISM
11. UPLATCH
12. 2-POSITION MECHANISM (MODE CHANGER)

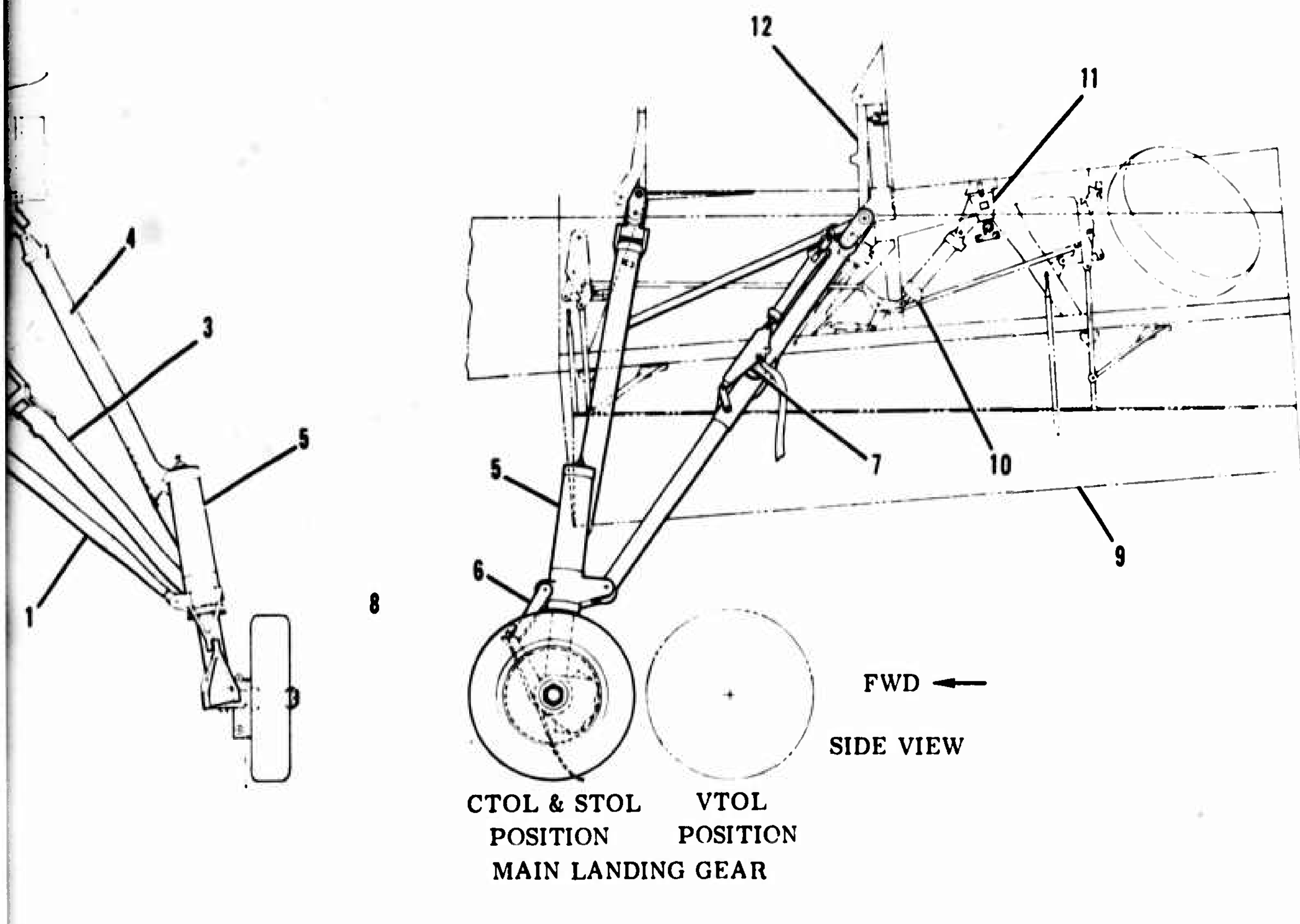


Figure 2.4 Aircraft Landing Gear Configuration

C

3.0 AIRCRAFT COOLING SYSTEM DESCRIPTION

The XV-5A aircraft cooling system has been provided to maintain safe operational temperatures for all aircraft structure and equipment during ground, flight, and wind tunnel testing, and during normal operation for both conventional and fan modes of operation. In the fan mode, the influence of the induced environment and the possibility of hot gas ingestion by the cooling system are matters of concern. They must be considered, despite the fact that only fragmentary data exist regarding the induced environment and its detailed nature. The gathering of definitive induced environmental data falls within the scope of flight research testing of the XV-5A aircraft and the lift fan concept.

The XV-5A cooling system consists of two generally parallel branches separated by a vertical plane through the aircraft centerline (BL=0) with occasional common ducting or plenums. Also, it is convenient to consider the cooling system as being made up of upper and lower fuselage sections separated by the cross hatched line shown in Figure 3.1. Referring to Figure 3.1, the primary motive power for each branch is supplied by two cooling air blowers; one large and one small. The blowers for each branch, housed in a common plenum (D), draw outside air from two fuselage ports supplying the plenum and from a slot formed by the rear cockpit canopy closure. This slot also acts as a second boundary layer bleed duct, and provides for cockpit (A) ventilation as well. Each smaller blower cools an electrical generator, a hydraulic oil cooler and the common electronic compartment (B) before dumping into the lower fuselage section (O). Each large blower supplies cooling air to its respective engine compartment (G) and the cross-over duct compartment (N) in proportionate amounts, dependent upon the mode of operation (turbojet or lift mode). Cooling air pumping is augmented by the tailpipe ejector action during turbojet mode operation, and by the pitch and wing fan cooling air ejector action during lift mode operation (Figure 3.2).

In the conventional mode of operation, two other systems take part in the cooling system (Figure 3.2). The boundary layer bleed duct opens to supply cooling air to the engine compartment, and the gas power distribution ducting acts as a branch of the cooling system with general flow from the pitch fan cavity to the wing fan cavities. As flight speed

increases, the boundary layer bleed air overpowers the large blower air flow, closes a flapper valve, and becomes the sole source of engine bay cooling air. With the flapper valve closed, the total large blower output is thus diverted to cross-over duct cooling, and to wing and pitch fan compartment cooling.

The flow path through the power distribution ducting is developed by the relatively high pressure at the pitch fan inlet closure system, and the low pressures developed over the wing fan inlet and outlet closure systems. Flow through the ducting system counteracts diverter valve leakage by providing direct mixing of leakage gases and cooling air flow before entering the wing fan cavities. Even with doors and louvers closed, sufficient cooling air exit flow area is provided from the fan cavity to maintain desired flow rates. The various components of the XV-5A cooling system are discussed in greater detail in the following subsections.

3.1 FORWARD UPPER FUSELAGE

3.1.1 Boundary Layer Bleed Duct

The boundary layer bleed duct, located between the engine inlet and fuselage as shown in Figure 3.3 is a ram inlet for the removal of the boundary layer formed on the canopy and fuselage forward of the turbojet engine inlet to improve the engine inlet performance. The ram air taken in is directed to the engine bays for cooling. The forward flapper at the inlet acts as a check valve to prevent engine suction applied at the boundary layer bleed duct inlet from reversing the flow through the duct during ground operations. A splitter aft of the forward flapper divides the flow from the single duct inlet into each individual engine bay. The duct branches, from the left and right hand large cooling fans, intersect the individual boundary layer bleed ducts leading to the left and right hand engine bays respectively. A flapper valve installed in each bleed duct at the branch intersection divides the flow between the ram air and the large cooling fan air in proportion to the static pressure and momentum forces developed on the flapper by each branch (see Section 9.3.3). As the aircraft increases speed, the ram air pressure from the bleed duct forces the flapper down and eventually shuts off this portion of the large cooling fan flow.

3.1.2 Cockpit Ventilation

Cockpit ventilation is provided by outside air drawn from the boundary layer into the cockpit. The air inlet is a gap around the canopy edge as presented in Figure 3.4. The canopy is sealed only on the forward top edge. The gap ranges from 0.1 inch on the sides to 0.5 inch at the hinge area. Air is withdrawn from the cockpit at the top of the aft canted bulkhead through the interconnecting ducting by suction of the cooling fans. Cockpit heat loads include contributions from the crew, cockpit equipment. aerodynamic heating, external heating by downwash, solar energy, forward and aft bulkheads and the floor over the pitch fan supply ducting. During VTOL operation, external hot gases from the fans may affect the temperature of the outside air entering the cockpit.

3.1.3 Cooling Fan Compartment

The cooling fan compartment is located aft of the hydraulic compartment and under the engine inlet, as presented in Figure 3.5. The compartment contains two large cooling fans, two small cooling fans, two generators, and the ducting for distribution of the cooling fan air flow. Cooling air enters the compartment from the cockpit and the two inlet ports, one on each side of the fuselage, and leaves the compartment through the various branches of the ducting system. The flow from the small cooling fans to the generators is recirculated in the compartment.

3.1.4 Cooling Fans

The major components of the cooling system are two centrifugal cooling fan assemblies. Each assembly is mechanically driven by its turbojet engine and consists of a gear box, one large centrifugal cooling fan, and one small centrifugal cooling fan, (Figure 3.5). The left and right hand cooling fan assemblies supply cooling air to the left and right hand side of the aircraft, respectively, in the upper fuselage section, and dump into the center fuselage section at the forward and aft bulkheads, respectively. The flow distribution of the four cooling fans is:

> L. H. large cooling fan flow supplies cooling air to the left engine bay and to the forward left side of the center fuselage section. The cooling fan air flow to the engine bay diminishes as flight speed increases until its total flow is discharged into the center fuselage section, (see Section 3.1.1).

R. H. large cooling fan flow supplies cooling air to the right engine bay and to the aft center of the center fuselage section. The flow characteristics to engine bay are the same as for the L. H. large fan.

L. H. small cooling fan flow supplies cooling air to the L. H. generator which discharges the flow back into the cooling fan compartment, and to the L. H. hydraulic oil cooler which discharges the flow into the electronic compartment.

R. H. small cooling fan flow distribution is the same as the L. H. small cooling fan, except that it supplies the R. H. generator and the R. H. hydraulic oil cooler.

3.1.5 Hydraulic Oil Cooler

There are two cross-flow hydraulic oil coolers (Stewart-Warner 8425A), one for each hydraulic system. Cooling air from the small cooling fans flow through the coolers and absorb heat from the hydraulic oil as it is returning to the reservoir. (For flow distribution, see Section 3.1.4.) For schematic, see Figures 3.2 and 3.5.

3.1.6 Electronic Compartment

The electronic compartment, located aft of the cockpit as presented in Figure 3.5, contains the radio, stability augmentation system, and various relays, switches, and other components of the electrical system. Cooling air is supplied from the small cooling fans to remove the heat of the electrical equipment. The cooling air leaves the compartment at the bottom, and is discharged into the lower forward fuselage section. The AN/ARC-51X radio has a built-in blower that draws cooling air from, and discharges it back to the electronic compartment.

3.1.7 Engine Compressor Compartment

The engine compressor compartment as presented in Figures 2.2 and 3.1 encloses the engine compressor, canular firewall surrounding the combustion chambers, and various engine accessories. The combustion chamber shroud extends into this compartment, however the shroud is open to the engine bay. Cooling air enters the compartment through holes in the ducting between the large cooling fans and the boundary layer bleed duct, and discharges through gaps around the four engine interstage bleed ducts.

3.1.8 Engine Bay

An engine bay is formed around each engine enclosing the turbine casing and diverter valve, as shown in Figures 2.2 and 3.1. The engine bays are separated from the center fuselage section, engine compressor compartment, and each other by titanium firewalls. The aft end is enclosed by an aluminum bulkhead and the outside surfaces are formed by a removable aluminum honeycomb panel. Cooling air enters the bay from the boundary layer bleed duct and the large cooling fans at the top inboard corner of the forward firewall, and is free to circulate around the complete surface of the turbine casing and diverter valve. A simple impingement baffle plate has been designed for installation at the engine bay inlet should subsequent tests indicate such redistribution to be desirable. A polished aluminum shield is installed around the tailpipe at the aft aluminum bulkhead to protect it from radiant heat. The cooling air discharges from the bay through the annulus formed by the tailpipe and shroud at the aft bulkhead, as shown in Figure 3.2.

3.2 AFT FUSELAGE

3.2.1 Aft Fuselage Bay

The aft fuselage bay contains the tailpipes, tailpipe shrouds, fuel cells, and control equipment. Because the quantity of heat given off by the tailpipe shrouds is low, and the heat sink formed by the fuel cells and skin surface is large, there is no requirement for cooling air to the aft fuselage bay.

3.2.2 Tailpipe and Shroud

The two tailpipes run diagonally through the aft fuselage, one from each engine, as shown in Figures 2.2 and 3.2. The tailpipes are shrouded the full length by individual titanium tubes forming an annular flow passage with a 1.5 inch gap. The inside of the shroud is gold plated to reduce the radiant heat transfer to the shroud. Cooling air from the engine bay flows through the annulus and to the ejector, cooling both the tailpipe and shroud, but primarily the latter.

3.2.3 Tailpipe Ejector

The tailpipe ejectors, located at the aft end of each tailpipe (Figures 3.2 and 3.6) consist of conical extensions of the shrouds past the tailpipe nozzles. The ejectors operate effectively only in the conventional flight

mode to increase the cooling air flow through the engine bay and tailpipe annulus. During operation with lift fan mode, only a small quantity of diverter valve leakage air enters the tailpipe, and cooling air flow is provided only by the large cooling fan.

3.2.4 Aft Equipment Compartment

The aft equipment compartment, (Figure 3.1), contains the electrical inverters and batteries. There is no cooling air requirement for this compartment, since no jet wake attachment to the outside skin is expected.

3.3 GAS POWER DISTRIBUTION SYSTEM

The gas power distribution system for the wing and nose fans is discussed here since it is the major source of heat to the center and forward fuselage sections, and the fan compartments.

3.3.1 Lift Fan Mode Operation

The hot gas generator exhaust gases are diverted through the diverter valve to the power distribution ducting in the center fuselage section, where they are distributed to the fan scrolls via three branches, with approximately 13% of the flow going to the pitch fan and 43.5% to each wing fan. The scrolls distribute the hot gas to the nozzle blocks, which discharge the gas evenly over the fan turbine blades. The ducting to the fan scrolls, and the scrolls, located in the wings and pitch fan cavity, are insulated with foil-covered Refrasil insulation blankets. The Marman-type clamps at the duct joints have a maximum leakage rate of 0.01 SCFM per inch of duct diameter. Due to contraction and expansion of the ducts, the leakage rate may be increased with operating time. The scroll seals extending around the inboard side of the wing fans and the aft side of the pitch fan have a General Electric guaranteed maximum leakage of 0.2% of the total hot gas flow. The scroll seal leakage may occur symmetrically around the seal or in localized areas.

3.3.2 Turbojet Mode Static Operation

During static operation in the conventional mode, the diverter valve is positioned in the straight through or turbojet mode position. The General Electric guaranteed maximum leakage of hot gases through the diverter valve to the fan mode ducting is 0.8% of the total gas flow, and it may or may not occur symmetrically around the valve. Thus, the leakage may

be distributed to each fan in the percentages given in Section 3.3.1, or if the leakage occurs on one side of the valve, the hot gases may attach to the duct walls and be distributed unevenly to the fans.

3.3.3 Turbojet Mode Flight Operation

During flight in the conventional mode, the diverter valve leakage into the cross-over duct is the same as that occurring statically, (refer to Section 3.3.2). During flight with the fan doors and louvers in the closed position, nearly ambient pressures are developed around the nose fan while negative pressures are developed over the wing fan louvers. The differential pressure so developed induces air flow from the pitch fan to the wing fan by way of the gas power distribution ducts. Air from the pitch fan cavity will mix with the hot diverter valve leakage gases in the cross-over duct before passing through the wing fan cavity to the outside.

3.4 LOWER FUSELAGE SECTION

The lower fuselage section consists of three compartments: the center fuselage compartment, flap actuator compartment, and the forward lower fuselage compartment. The lower fuselage section is that portion of fuselage under the engine bays, main fuel cell, electronic compartment, and cockpit as shown in Figure 3.2. This section of fuselage contains the cross-over and pitch fan ducting, electrical and hydraulic equipment, engine controls, aircraft control system components, and fire extinguisher bottles. The heat sources to this section include: conduction, radiation and convection from the shrouded ducting, recirculation of heated cooling air, hot gas leakage from ducting joints, and external hot gas leakage into the compartment caused by lift fan stream impingement on the skin.

3.4.1 Center Fuselage Compartment

The center fuselage compartment located under the engine bays as noted in Figures 2.2, 3.1, 3.2 and 3.7 is supplied with cooling air from the large cooling fans, (Section 3.1.4). The compartment skin is formed by a series of unsealed removable panels, which offer the possibility of cooling air leakage from the compartment and hot gas leakage into the compartment. The cooling air leaves the compartment through the flap actuator compartment, and through the scroll cavities of the wing roots to the wing fan ejectors. During conventional operation, the diverter valve gas leakage does not cause a serious heating problem in the center fuselage compartment.

3.4.2 Flap Actuator Compartment

The flap actuator compartment is located aft of the wing rear spar in the fuselage as presented in Figure 3.7. There is no cooling requirement for this compartment during CTOL mode. During VTOL mode, hot gases from the wing fan exhaust may have a tendency to enter the compartment through the slots provided for the flap actuator shafts. On the other hand, opposing the hot gas inflow is the cooling air which enters the compartment from the center fuselage through the control cable holes in the rear spar and which discharges to the outside through the slots mentioned above.

3.4.3 Forward Lower Fuselage Compartment

The forward lower fuselage compartment is that portion of the fuselage under the main fuel cell, electronic compartment, and cockpit as shown in Figures 2.2, 3.1 and 3.2. Cooling air is supplied to this compartment from the small cooling fans discharging from the electronic bay, (refer to Section 3.1.6). For the compartment equipment and heat sources, see Section 3.4. In the portion of the compartment labeled "O" in Figure 3.1, the flow will go aft towards the center fuselage. The leakage rate around the panels is assumed to be such that all the flow will leak outside before reaching the center fuselage, although there may be interchange of flow between the two compartments. The portion of the compartment labeled "P" in Figure 3.1 is divided into two parallel sections separated by the nose landing gear compartment, as presented in Figure 2.2. The cooling air in this portion will flow forward to the nose fan compartment along the nose fan ducts.

3.5 NOSE FAN COMPARTMENT AND CAVITY

3.5.1 Nose Fan Compartment

The nose fan compartment, located forward of the cockpit front bulkhead as presented in Figures 2.2 and 3.1, contains the nose fan, fan ducts and fan scroll. The heat sources in the compartment are: conduction, convection, and radiation from the fan, ducts and scroll; fan scroll seal leakage; duct joint leakage; and external hot gases impinging on the compartment skin. Cooling air enters the compartment from the forward lower fuselage compartment and discharges through the nose fan air ejectors.

3.5.2 Nose Fan Air Ejectors

The nose fan air ejectors consist of slots cut into the nose fan inlet louver support struts running fore and aft across the bellmouth. During operation in the lift fan mode, the high velocity air flowing over the struts to the nose fan creates a low static pressure at the slots, thereby developing a differential pressure across the nose fan compartment cooling system. The ejector does not operate in the conventional mode.

3.5.3 Nose Fan Cavity

The nose fan cavity extends vertically through the aircraft nose from the fan inlet louvers to the fan exhaust doors (thrust reverser doors) as presented in Figure 3.1. During operation in the lift fan mode, the hot gases exhaust from the bottom aft quadrants of the fan and impinge on the aft cavity wall where a partial mixing of the cold and hot gas takes place. The aft wall is made of titanium to withstand the high temperature gases. During static operation in the conventional mode, the air ejector is nonoperative and the only cooling air is a relatively small amount supplied from the fuselage, which is at a slightly higher pressure. Because there is no method provided for purging the cavity of diverter valve leakage, the inlet louvers and thrust reverser doors should be left open during ground runs. During conventional flight, air entering the cavity through gaps in the inlet louvers will mix with the cool air from the fuselage and discharge through the nose fan supply ducts to the wing fan cavities, (see Section 3.3.3). No serious heating problems are expected in the nose fan cavity during flight operation in the conventional mode.

3.6 WING FAN COMPARTMENT AND CAVITIES

3.6.1 Wing Fan Compartments

The wing fan compartments in each wing are bounded by the front and rear wing spars, the wing root, and the rib at BL 100 as shown in Figure 3.8. The compartment contains the wing fan and scroll. The heating sources are the same as the nose fan cavity, (refer to Section 3.5.1). Cooling air is supplied from the center fuselage and discharged through the wing fan air ejectors to the wing cavity.

3.6.2 Wing Fan Air Ejectors

The two air ejectors on each wing fan are located on the fan strut running fore and aft on the fan centerline and across the bellmouth as presented in Figure 3.9. During operation in the lift fan mode, the high velocity cold air entering the wing fan creates a low static pressure at the ejectors, therefore developing a differential pressure across the wing fan compartment cooling system. The air ejectors are non-operative during conventional operation.

3.6.3 Wing Fan Cavities

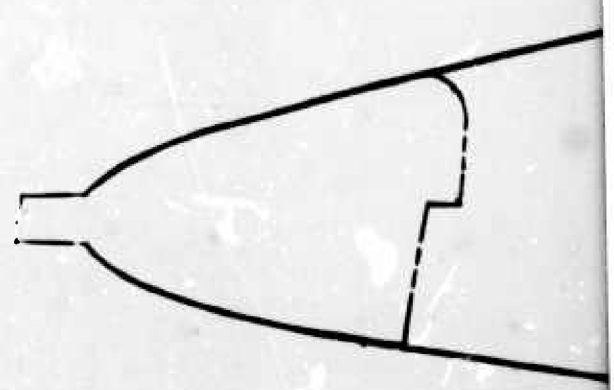
The wing fan cavities extend vertically through each wing from the inlet doors to the exhaust louvers as presented in Figures 2.2 and 3.9. During operation in the lift fan mode, some recirculation of wing-fan, tip-turbine exhaust gases may occur at high angle of attack and in ground effect. During conventional mode operation, the characteristics of the flow are the same as and diverter valve leakage gases are confined as in the nose fan cavities (see Section 3.5.3). During conventional flight, a low external pressure is developed over the fan doors and louvers. These low pressures create a low pressure in the cavity to aid cooling air flow from the fuselage and nose fan cavity, (see Section 3.3.3).

SECTIONS & COMPARTMENTS

A	COCKPIT
B	ELECTRONIC COMPT
C	HYDRAULIC COMPT
D	COOLING FAN COMPT
E	ENGINE INLET & BOUNDARY LAYER BLEED SECTION
F	ENGINE COMPRESSOR COMPT
G	ENGINE BAY
H	TAIL PIPE & SHROUD SECTION
J	AFT FUSELAGE COMPT
K	AFT EQUIPMENT COMPT
L	MAIN LANDING GEAR COMPT
M	FLAP ACTUATOR COMPT
N	CENTER FUSELAGE COMPT
O	FWD LOWER FUSELAGE COMPT
P	FWD LOWER FUSELAGE COMPT
Q	PITCH FAN COMPT
R	PITCH FAN CAVITY
S	DRAG CHUTE COMPT
T	TAIL SECTION

COM

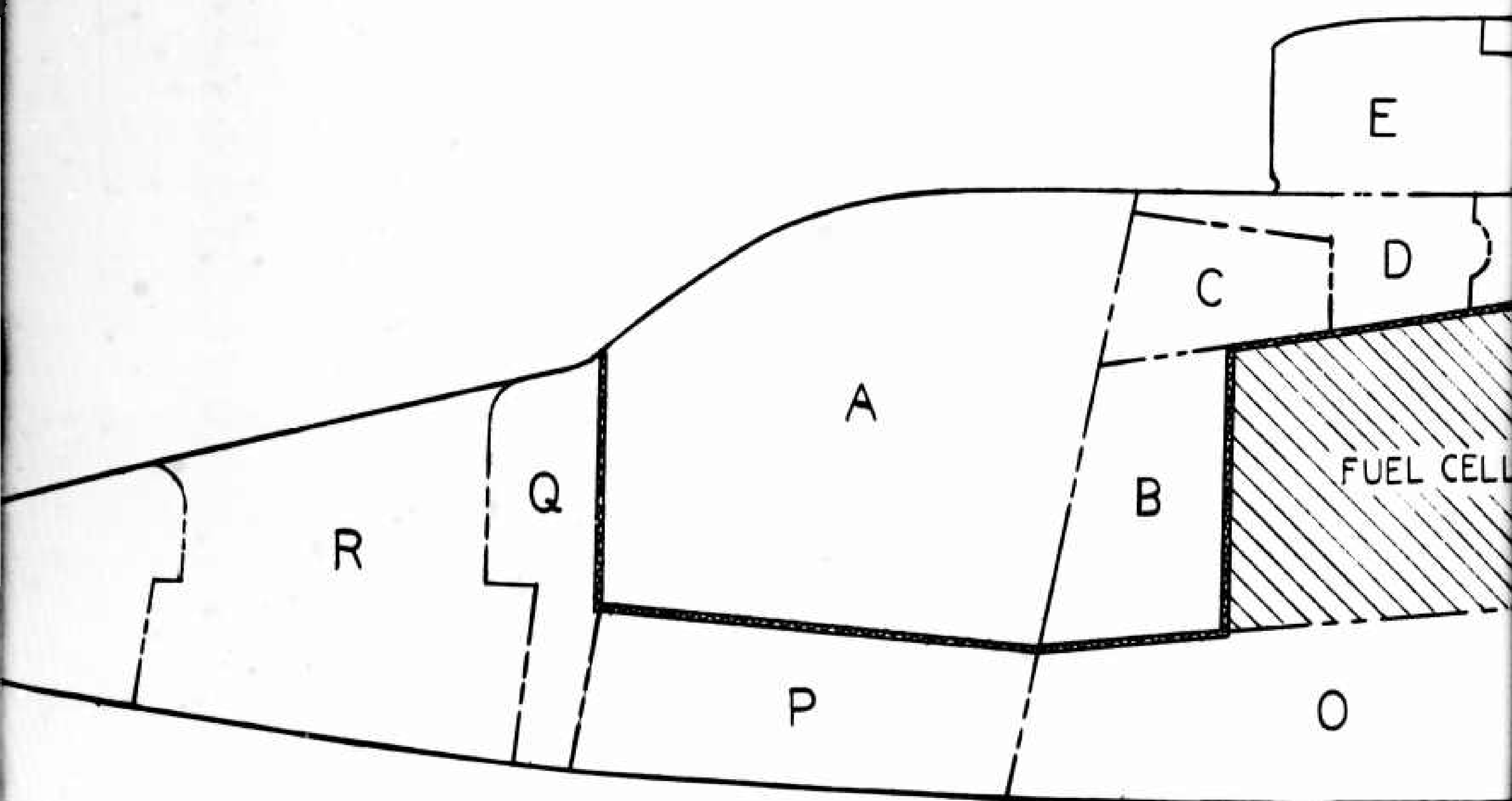
BOU



A

COMPT. BOUNDARIES

BOUNDARY BETWEEN UPPER & LOWER FUSELAGE



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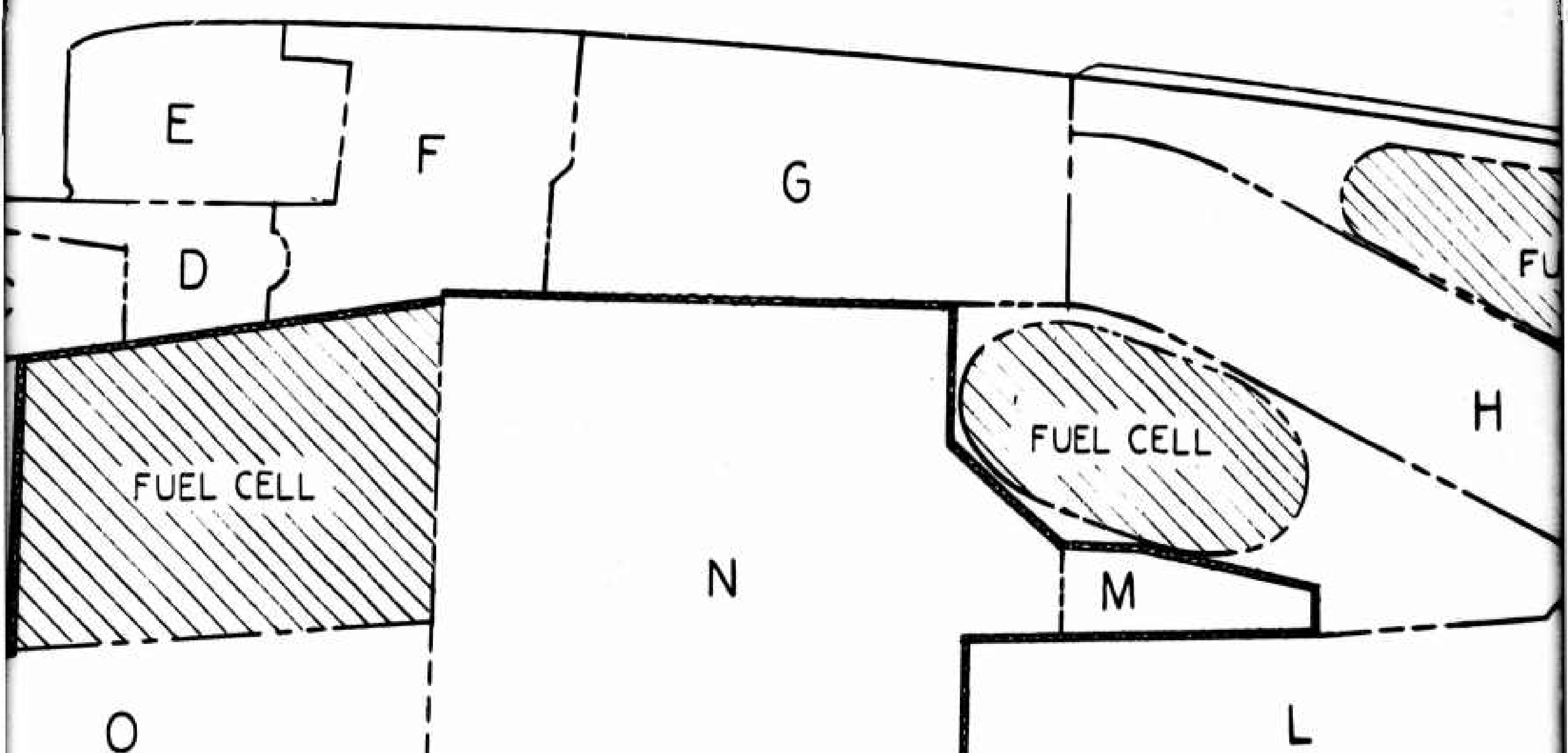
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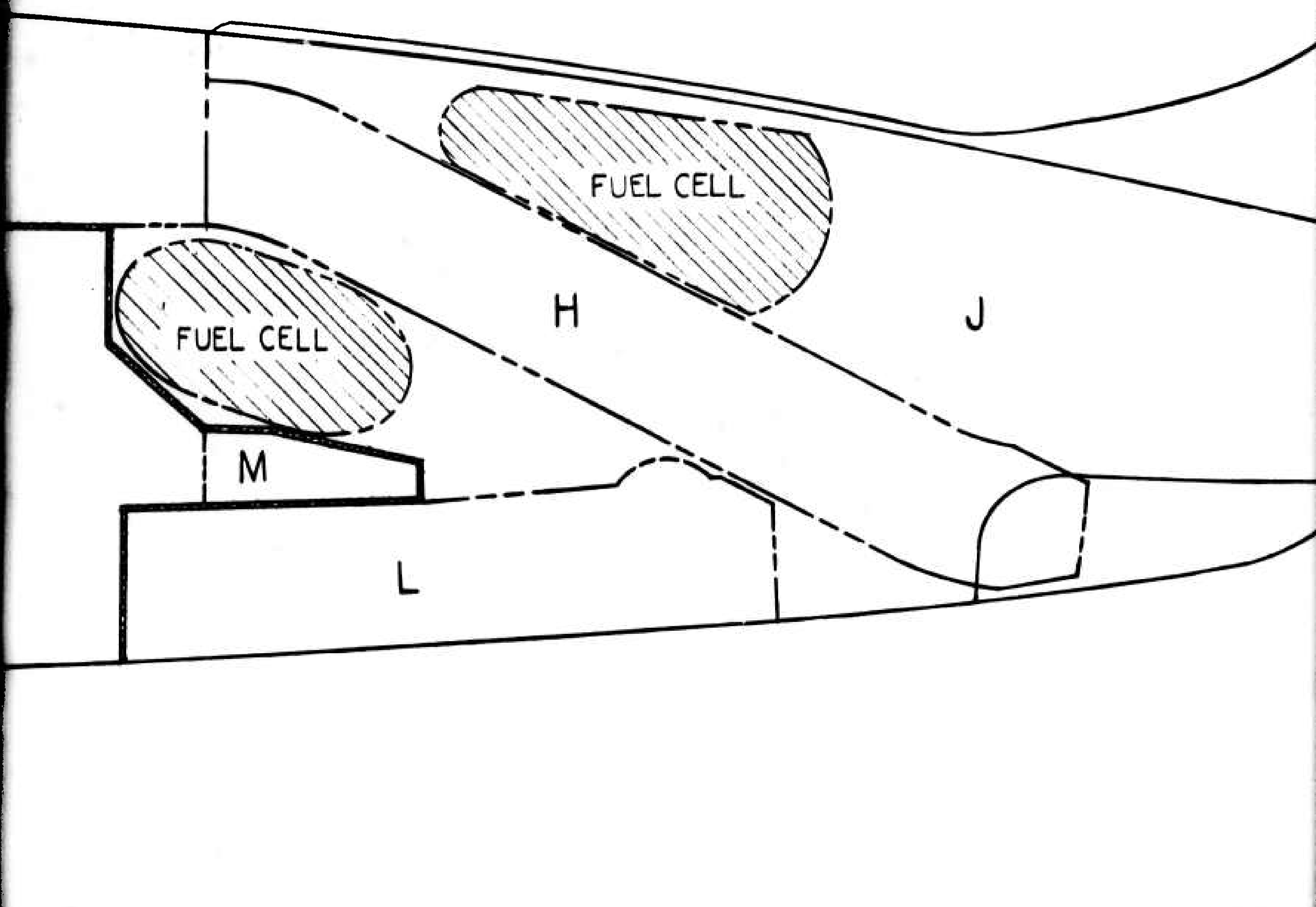

Figure 3.1

D

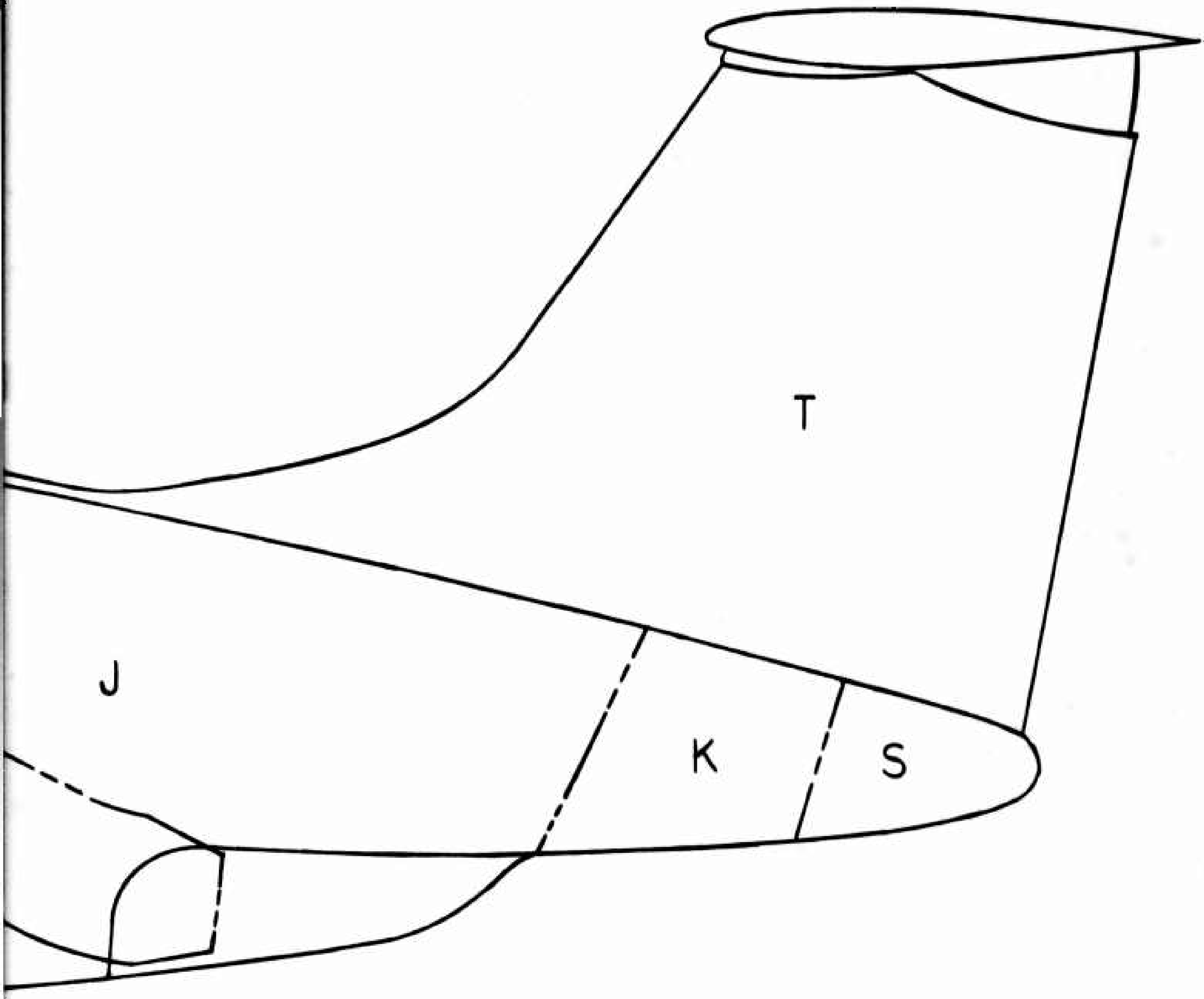

Figure 3.1 General Arrangement - Fuselage Section and Compartments

E

General Arrangement

A	Engine Inlet
B	Boundary Layer Bleed Duct
C	Cooling Fan Compartment Air Inlet
D	Cockpit Air Inlet
E	Cooling Fans
F	Hydraulic Pump and Generator
G	Hydraulic Oil Cooler
H	Electronic Bay
J	Small Cooling Fan Ducting
K	Cooling Fan Compartment
L	Duct - Cockpit to Cooling Fan Compartment
M	Cockpit
N	Aft Pitch Fan Compartment
O	Pitch Fan Air Ejector
P	Pitch Fan Cavity
Q	Pitch Fan
R	Pitch Fan Doors - Lower
S	Pitch Fan Doors - Upper
T	Turbine Casing
U	Engine Bay
V	Diverter Valve
W	Tailpipe Shroud
X	Tailpipe
Y	Boundary Layer Bleed Duct Flappers
Z	Large Cooling Fan Ducting
AA	Thrust Spoiler
BB	Flap Actuator Slot
CC	Cross-Over Ducts
DD	Tailpipe Ejector
EE	Lower Fuselage Cavity
FF	Pitch Fan Supply Duct
GG	Forward Wing Spar
HH	Aft Wing Spar
JJ	Aft Wing Fan Air Ejector
KK	Forward Wing Fan Air Ejector
LL	Wing Fan
MM	Wing Fan Scroll

Cooling and Engine Air Flows

1	Outside to Cockpit
2	Outside to Boundary Layer Bleed Duct
3	Engine Inlet
4	Outside to Cooling Fan Compartment
5	Small Fans to Hydraulic Oil Coolers and Electronic Bay
6	Boundary Layer Bleed Duct to Engine Bays
7	Large Cooling Fans to Engine Bays
8	Small Cooling Fans to Generators
9	Cockpit to Cooling Fan Compartment
10	Left Hand Large Blower to Fuselage Cavity
11	Right Hand Large Blower to Fuselage Cavity
12	Engine Bays to Tailpipe Ejectors
13	Engine Diverter Valves to Cross-over Ducts
14	Cross-over Ducts to Wing Fans
15	Cross-over Ducts to Pitch Fans
16	Pitch Fan to Wing Fans
17	Pitch Fan Aft Compartment to Pitch Fan Air Ejectors
18	Outside to Pitch Fan Cavity
19	Pitch Fan Cavity to Outside
20	Outside to Pitch Fan Cavity
21	Pitch Fan Cavity to Outside
22	Fuselage Cavity to Flap Actuator Slots to Outside
23	Engine Exhaust
24	Electronic Bay to Aft Pitch Fan Com-Partment and Fuselage
25	Fuselage Cavity to Forward Wing Fan Air Ejectors
26	Fuselage Cavity to Aft Wing Fan Air Ejectors
27	Wing Fan Cavity to Outside

A

Air Flows

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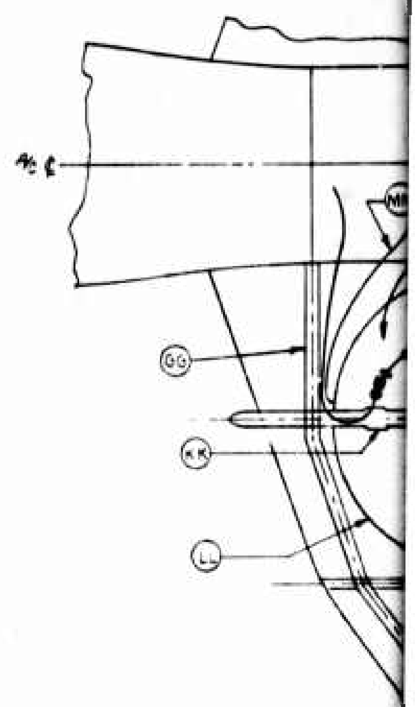

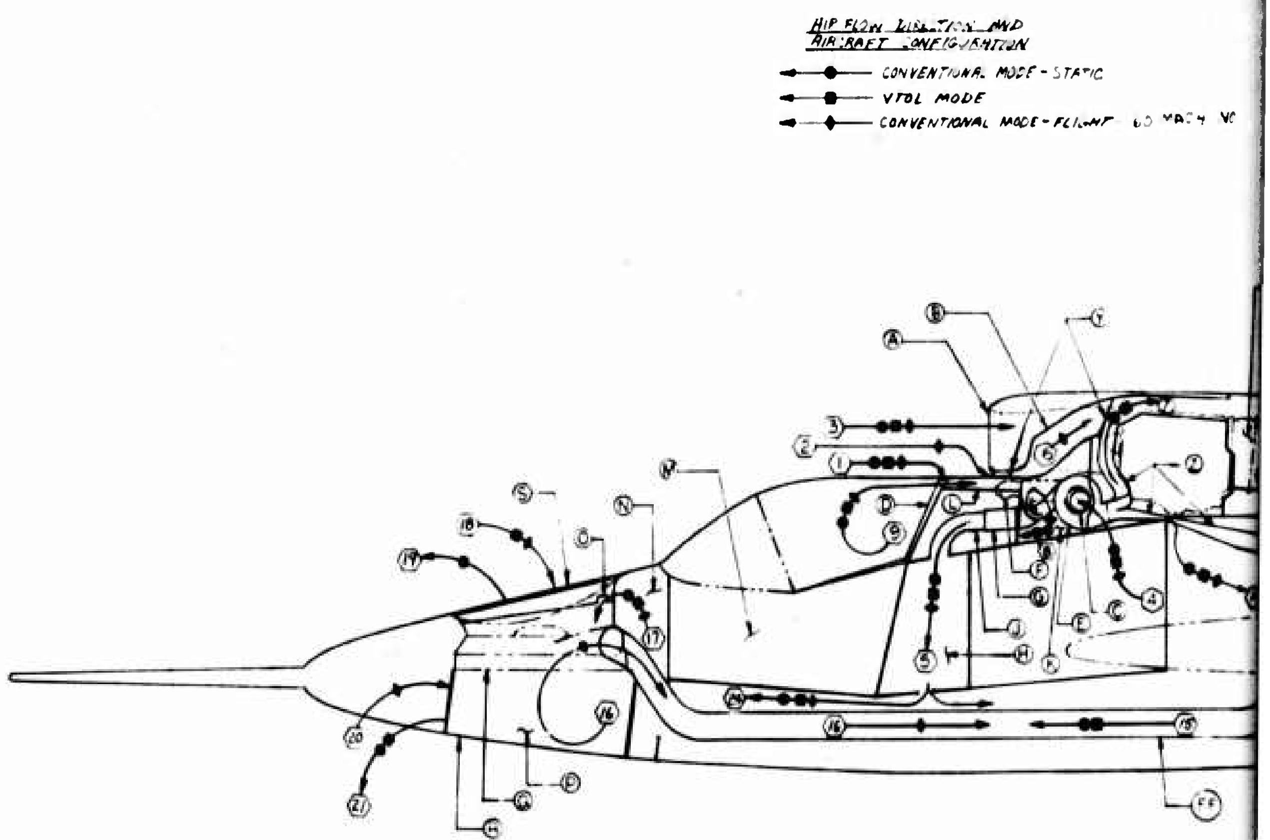

SIDE VIEW

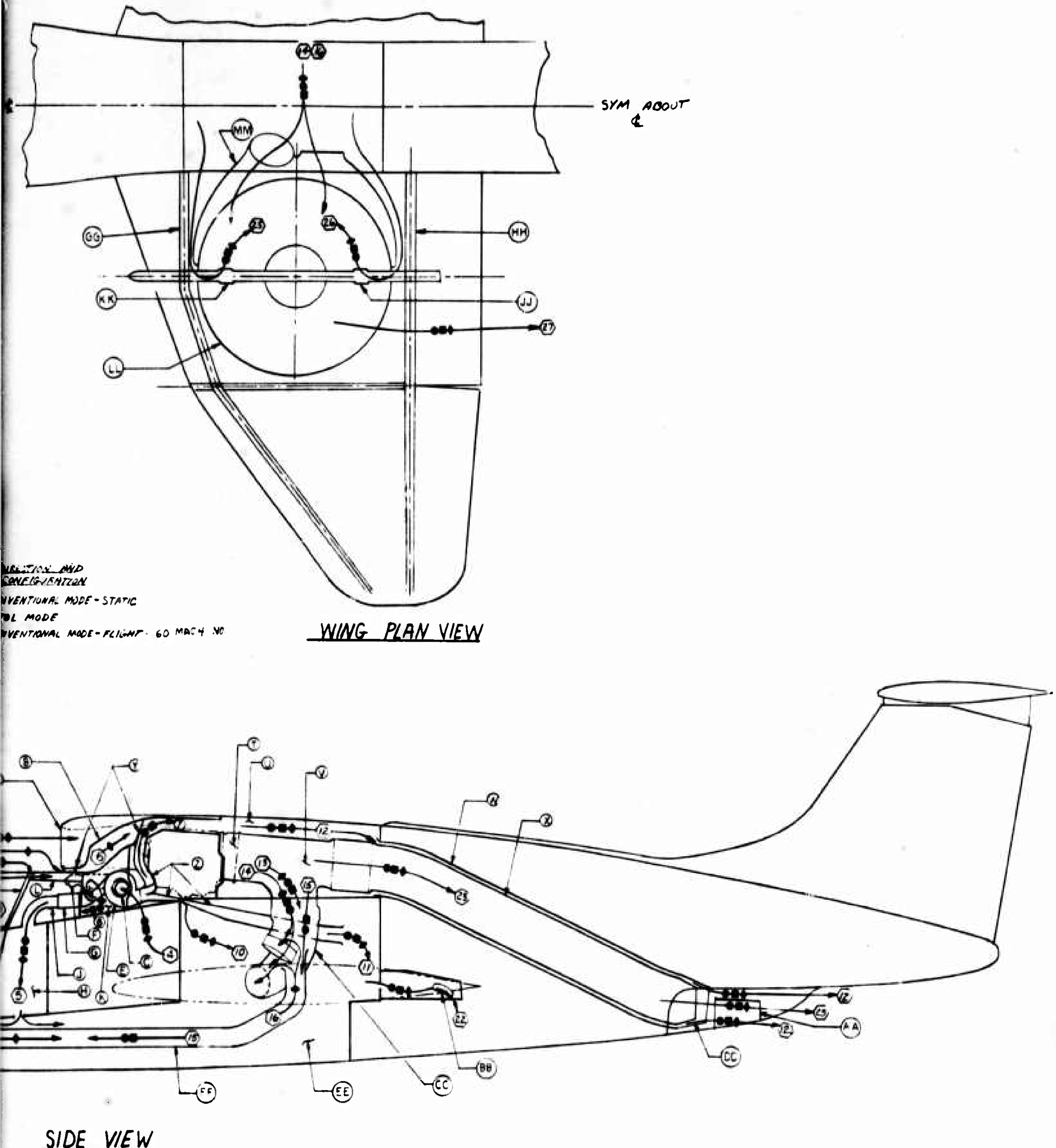

Figure 3.2 General Arrangement - Cooling and Engine Air Flow

C

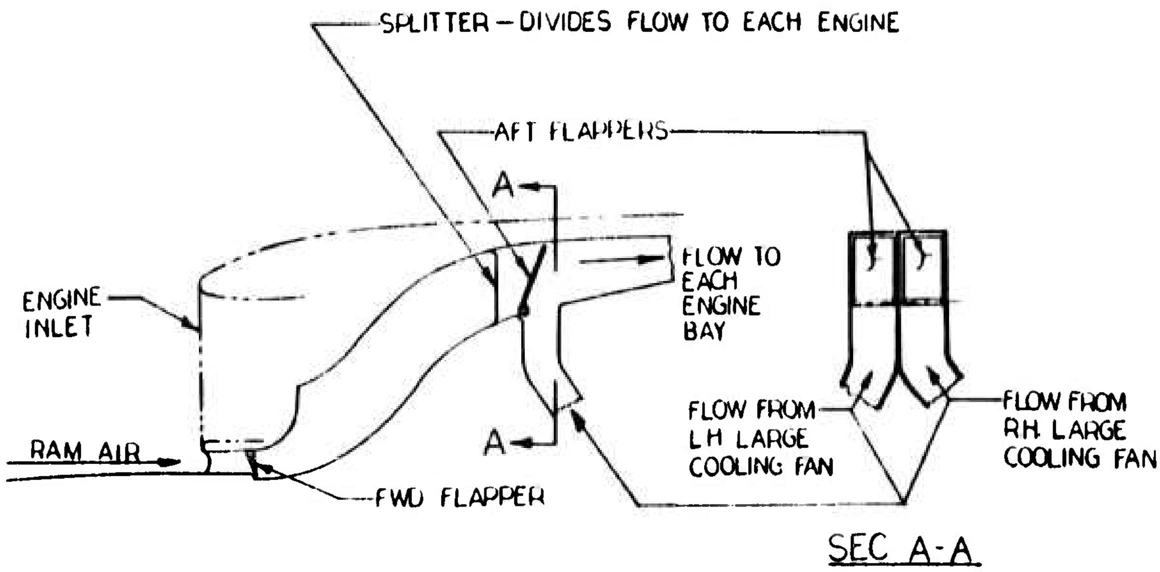

Figure 3.3 Heating and Cooling Schematic - Boundary Layer Bleed Duct

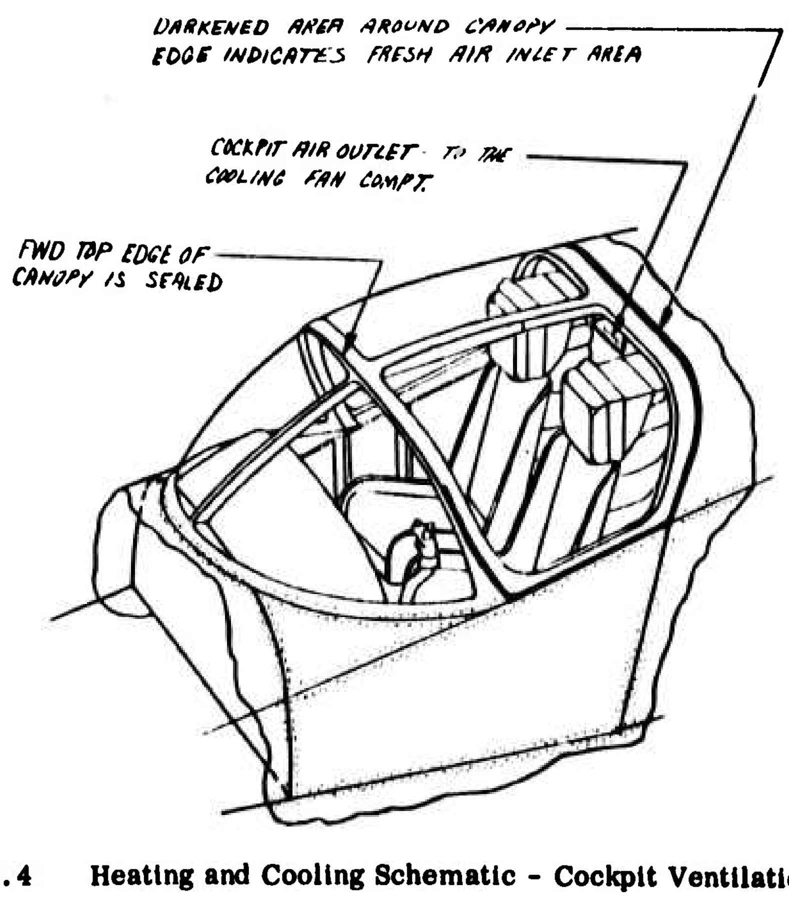

Figure 3.4 Heating and Cooling Schematic - Cockpit Ventilation System

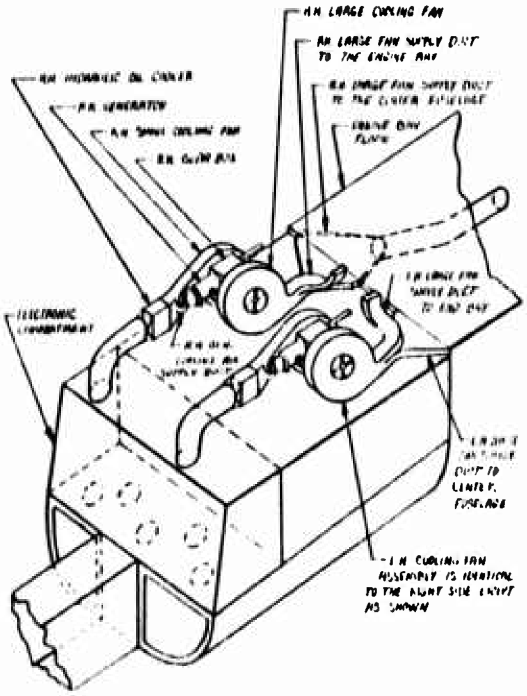

Figure 3.5 **Heating and Cooling Schematic - Cooling Fan, Hydraulic and Electronic Compartments**

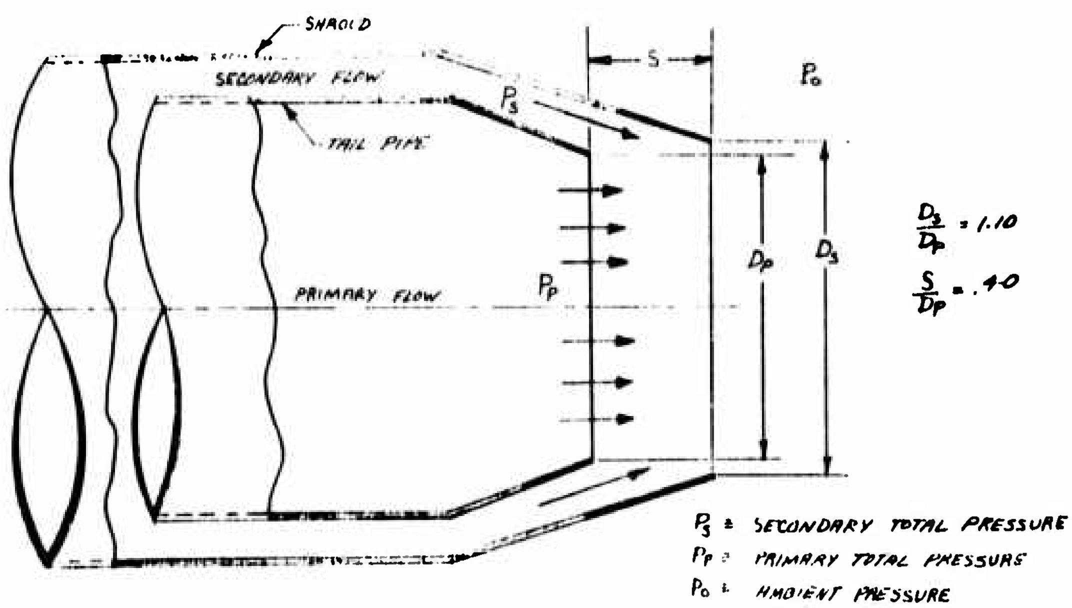

Figure 3.6 **Heating and Cooling Schematic - Tail Pipe Ejector**

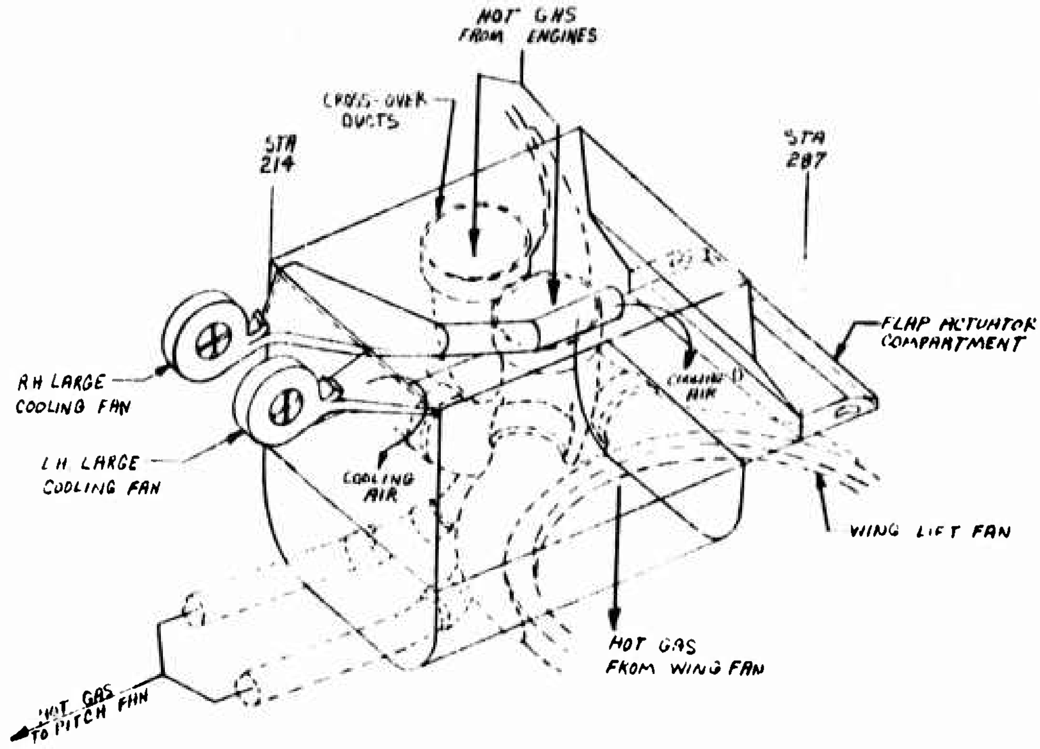

Figure 3.7 Heating and Cooling Schematic - Center Fuselage

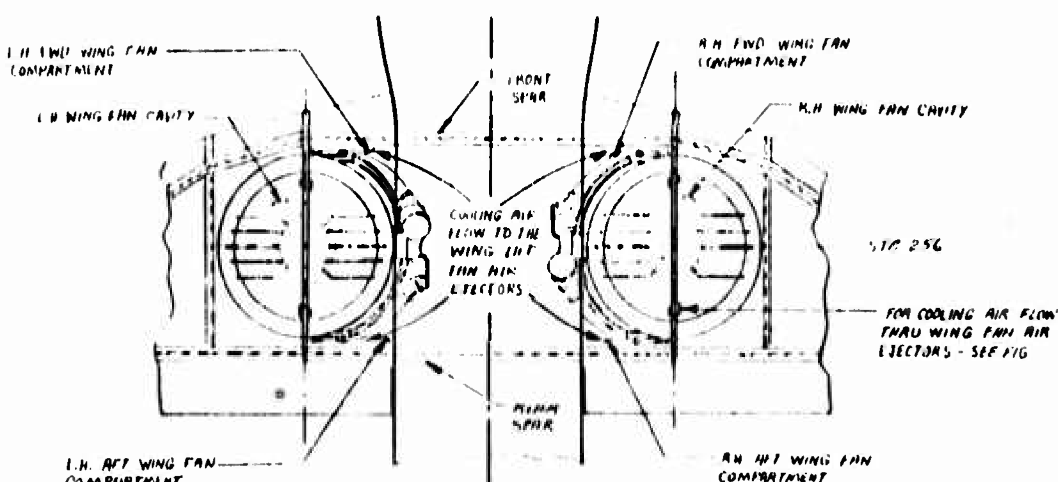

Figure 3.8 Heating and Cooling Schematic - Wing Lift Fans

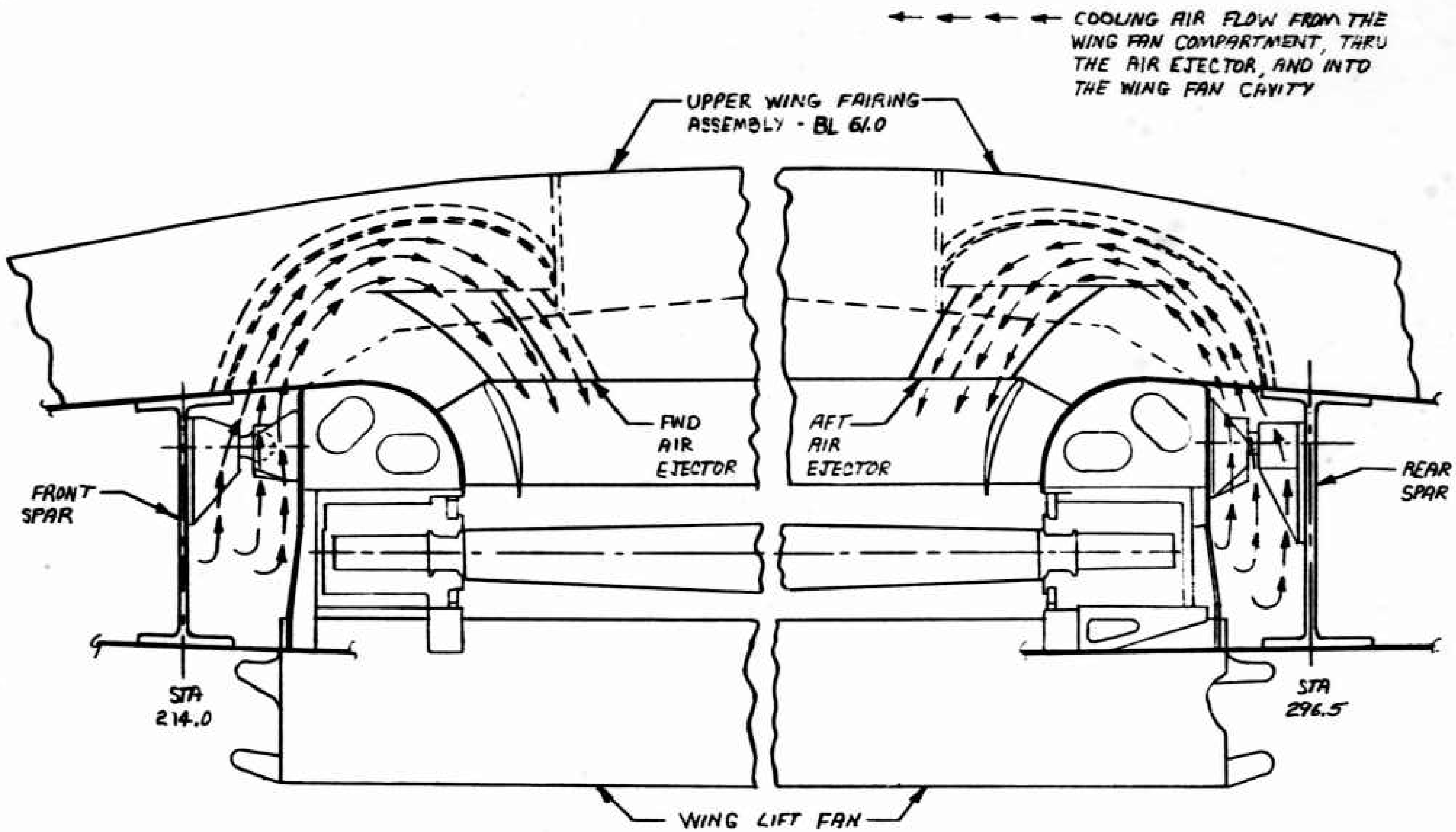

Figure 3.9 Heating and Cooling Schematic - Wing Lift Fan Air Ejectors

4.0 REQUIREMENTS

4.1 GENERAL OBJECTIVES

The general objectives of the XV-5A cooling and structural protection systems are to maintain aircraft component and structural temperatures within safe limits for the following operational conditions which are listed in order of expected increasing severity.

a. Normal operation

b. Ground checkout tests

c. Wind tunnel test

d. Prolonged flight test in and out of ground effect.

Flight test is considered to include fan and turbojet mode operation, conversion sequences, and ground runs, where extended test durations are required.

4.2 DESIGN CRITERIA

Design load and off-design load temperature limits for structural materials are summarized in Table 4.1. Under light loadings at off-design conditions, the design load limits may be relaxed and temperature limits increased to those values at which no appreciable permanent loss of strength is experienced. A number of aircraft component temperature limits are summarized in Table 4.2 and Figure 4.1.

4.3 OPERATIONAL CRITERIA

The XV-5A operational design criteria are summarized in Table 4.3. Their establishment considered extended ground, wind tunnel, and flight test operations as well as pilot training and flight familiarization programs. From a heating and cooling viewpoint, the criteria of Table 4.3 are expected to be more severe than actual conditions when the XV-5A becomes operational.

TABLE 4.1

XV-5A Aircraft, Structural Temperature Limits

	Design	1 g Load
Aluminum Alloys	250° F	325° F
Titanium -99 T_c	550° F	1000° F
6AL4V	700° F	1100° F
Magnesium AZ318H24	250° F	400° F
Steel - Marage	300° F	700° F
Fiberglas Laminate - Silicone	700° F	700° F
Rubber - Silicone	450° F	450° F

TABLE 4.2

XV-5A Aircraft, Component Temperature Limits

Power Plant Temperature Limits

EGT	Starting 1 second	950° C	1742° F
	4 seconds	850° C	1562° F
	11 seconds	750° C	1382° F
	Steady State 100% RPM	680° C	1256° F
	Steady State Idle	600° C	1112° F
EGT	Fluctuation	+5, -10° C	+9, -18° F
Oil Temp.	Tank	177° C	(350° F)
Fuel Inlet		43° C	110° F
Casing			
	Fwd. Compressor		250° F
	Aft Compressor and Main Frame		750° F
	Combustor		850° F

TABLE 4.2 (Continued)

Turbine Case	1150° F
Diverter Valve	1300° F
Diverter Valve Actuator Oil-In	200° F
X353-5B Wing Fan	
Bearing	350° F
Rotor (Turbojet Mode)	250° F
Front Frame (Outboard Side)	300° F
X376 Pitch Fan	
Bearings	350° F
Front Frame	250° F

Engine Component Limit

Ignition Generator	350° F
T5 Harness Disconnect	350° F
Power Pack	300° F
Tachometer-Generator Alternates	285° F
Anti-Icing Valve	275° F
Junction Box	300° F

All other engine components are designed for continuous operation when surrounded by air at an ambient temperature of 250° F.

Electronic Components

Environment	160° F
AN/ARC 51X Radio (See Figure 4.1)	131° F

TABLE 4.3

XV-5A Aircraft, Operational Criteria

Case	Operation or Test	Time Min.	Mode	J85 SP'D % RPM	h/D	V_p Knots	β_v°	Landing Gear	Thrust Spoiler*	Fan Turbine Exhaust Temp. °F**
a	Ground Check	5	Fan	<86	1.0	0	45 to -5	Down	----	800
b	Ground Check	1.5 after 5 min. @ (a)	Fan	100	1.0	0	0	Down	----	1000
c	Flight Test	20* after 5 @ (a)	Fan Hover	100	>3	0	0	Down	----	1000
d	Flight Test	20* after 5 @ (a)	Fan Flight	100	>3	0-80	0 to 35	Down	----	1000
e	Flight Test	5 after 5 @ (d)	Fan Flight	100	>3	80-100	35 to 45	Down	----	1000
f	Flight Test	20	Fan Taxi	86	1.0	0-60	0 to 35	Down	----	800
g	Flight Test	0.5 after 5 @ (a)	Fan STOL	100	1.0	0-80	0-40	Down	----	1000
h	Flight Test Thrust Spoiler	2	Conventional	100	>3	120	90	Down	0-75	
i	Ground Test	Indefinite*	Conventional	All	1.0	120	90	Down	----	
j	Flight Test	Indefinite*		All	>1.0	All	90	Up	----	

* or until minimum fuel reserve is reached, whichever is less.
** based on NASA-Ames and recent Ryan XV-5A test data.

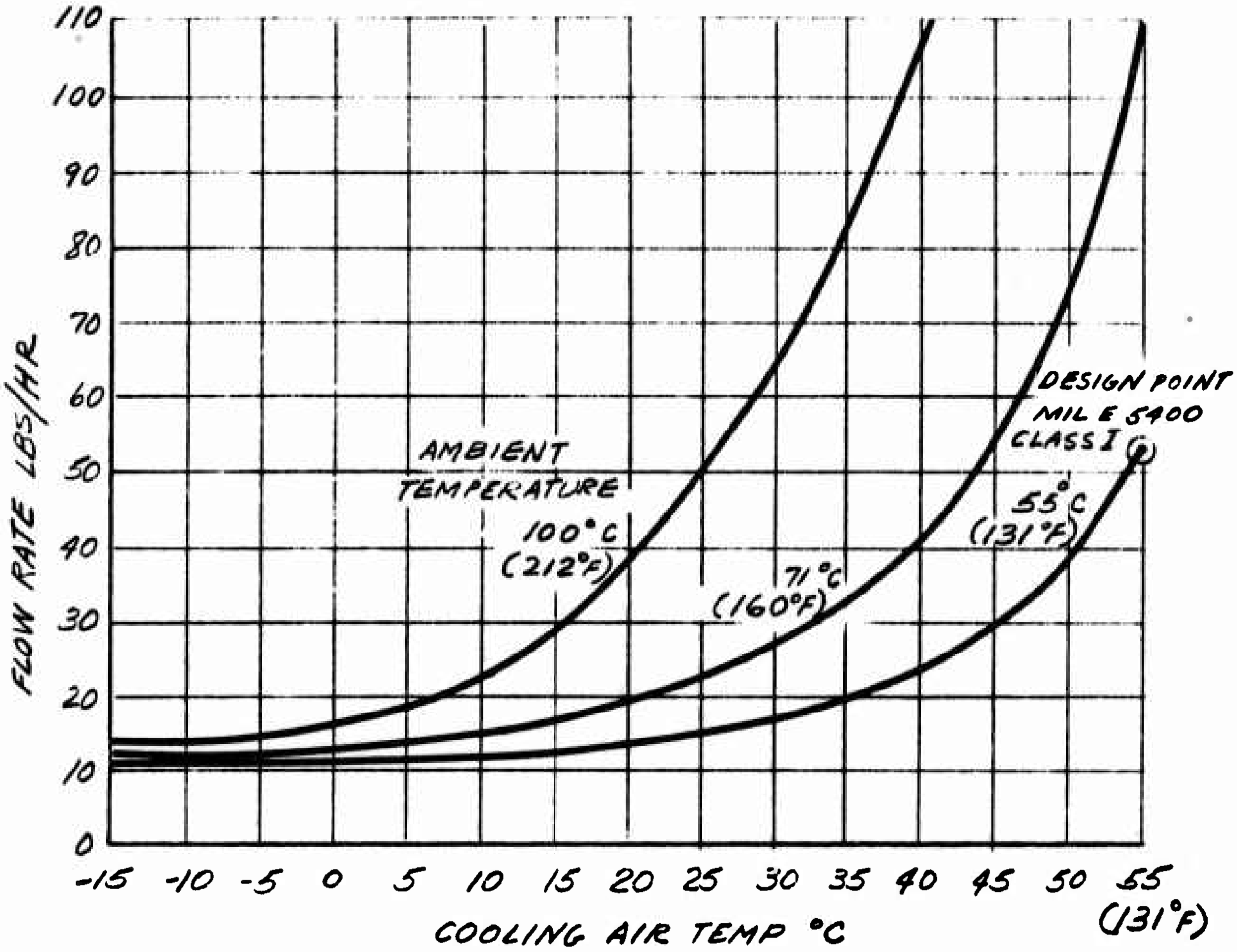

Figure 4.1 Cooling Air Requirements, AN/ARC-51 Radio (10-Minute Receive/ 5-Minute Transmit Duty Cycle)

RYAN 64B017

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5.0 AIRCRAFT ENVIRONMENT

5.1 CLIMATIC EXTREMES

Provisions for climatic extremes are incorporated in the XV-5A aircraft to the extent specified by Reference 1 which requires that the aircraft operate satisfactorily in a temperature environment from -40° F to 135° F. A maximum ambient temperature of 94° F has been used to establish aircraft design requirements and performance.

5.2 INDUCED ENVIRONMENT, TURBOJET MODE

5.2.1 Normal Operation

During normal operation in the turbojet mode, the external environment of the aircraft will be essentially ambient conditions as for conventional aircraft.

5.2.2 Thrust Spoiler Operation

During thrust spoiler operation, the lower portions of the aft fuselage section will be exposed to turbojet exhaust gases to 1250° F. Based on data of Figure 5.1, estimated hot gas isotherms are presented in Figure 5.2.

5.3 INDUCED ENVIRONMENT, FAN MODE

5.3.1 Background

The induced environment surrounding the XV-5A aircraft during fan mode operation affects many aspects of the aircraft design, performance and operation because of (1) local heating, (2) hot gas and /or particle ingestion by propulsion and cooling systems, and (3) force and moment self-disturbance phenomena. These effects are most evident in ground effect, however, some are present out of ground effect also.

In spite of rather extensive literature on downwash phenomena (see table 5.1 for definition of terms), including theoretical and experimental studies on small and large scale components, much is lacking for understanding, estimating and evaluating induced flow fields for a new

aircraft. Data of Kuhn, Newsom, and Tosti (References 2-4) give useful insights regarding the flow fields for particular aircraft configurations tested, and may be combined with generalized correlations to develop quantitative estimates of some flow field characteristics. The data of Hess (Reference 5) are useful for far field effects. Because of its importance, the remainder of Section 5.3 attempts to develop some of the nature and character of the induced environment as it affects the XV-5A aircraft.

5.3.2 General Characteristics

Each fan can be idealized as an area source-sink combination such that the fan slipstream ultimately returns to its inlet, forming a closed loop flow field symmetrical about the fan plane. Adding the effects of multiple fan slipstreams, slipstream vectoring, unequal slipstream intensities, uniform wind velocities, surface impingement, and other factors, complicates the problem of defining the resulting flow field details, but does not alter its basic closed loop character. In a real gas, the closed loop flow field does not develop unless additional forces are present, such as those developed from ground planes or other sources.

If the XV-5A aircraft is hovering far above the ground plane, its fan streams at first maintain their separate identity, then gradually coalesce to form one large "aircraft-slipstream" and finally dissipate before striking the ground. As the aircraft approaches the ground plane, the "aircraft-slipstream" begins to "feel bottom" and is turned to run radially outward from its impingement center. Details of the radial flow field for this condition can be approximated using suitable assumptions and the generalized data of Kuhn (reference 4) as presented in Figure 5.3. When the aircraft is very close to the ground, the individual fan slipstreams "feel bottom" before coalescence, and are turned to run radially along the ground plane from their respective impingement centers. The radially running ground streams from the inboard or facing fan stream quadrants meet to form an interaction zone where the streams are deflected forward, upward, or aft in a complex manner.

In addition to the above, the engine air and cooling air system inlets act as sinks to further distort and modify the local aircraft flow fields. Considering the effects of the modulatory turning of the nose fan slipstream for pitch control, differential main fan intensity and velocity vectoring for roll and yaw control, collective vectoring for translational flight, and winds from any direction, the extreme complexity of the local flow field near the aircraft is evident.

5.3.3 Interaction of Multiple Fan Streams

When two adjacent and identical fan slipstreams impinge normal to a ground plane, the radially flowing ground streams encounter each other along a line midway between the slipstream impingement centers and normal to the line connecting their centers such as shown in Figure 5.4(a). Along this line, the speed (and dynamic pressure) of the encountering streams are assumed to be equal, therefore, there should be no net flow across the line or zone of interaction.

From the characteristic velocity decay rates of Figure 5.3, it can be seen if one of the streams is stronger than the other, the interaction zone will be displaced toward the weaker stream. Such effects depend on relative fan diameters, spacing, and slipstream intensities as shown in Figures 5.4(b), (c) and (d). Likewise, differentially vectoring the fan streams will move their impingement centers in the direction of vectoring, distort their outflow pattern from circular to elliptical, and will "skew" the interaction zone away from the more powerful side of the outflow pattern as indicated by Figure 5.4(e).

If a third fan slipstream is added to form a triangular pattern, the flow field is materially altered and new interaction zones are formed, again depending upon the fan spacing, diameter, and fan stream intensity. Figures 5.5(a), (b), and (c) show representative interaction zones for equal diameter fans having identical fan stream intensities. The effects of different intensities, diameters, and differential vectoring are shown in Figures 5.5(d) through 5.5(h). Unfortunately no known data exist which permit quantitative estimates of vectoring effects. Various methods of approximation are being considered, however, they are not developed to the point so that inclusion in this report can be justified.

The above procedure may be used as a first approximation to estimate the effect of ground winds as shown in Figure 5.6. The presence of such an interaction zone suggests the possibility of potential reingestion and the formation of at least a partially closed loop flow system.

Flow field studies on a model of the twin-prop VZ-2 (Reference 2) suggest the behavior of the ground flow at the interaction zones. If the angle of attack of the streams to the interaction zone is from about 70 to 90°, flow will be turned strongly upward at angles from 45 to 90°. If the angle of attack is less than about 70°, the upturn angle drops to 10° or less, and the encountering streams tend to join and run more or less parallel to each other along ground at the interaction zone.

5.3.4 Some Quantitative Estimates of XV-5A Downwash Phenomena

During hovering operation, the XV-5A is supported by lift developed by two 62.5" diameter wing fans, the centers of which are approximately two fan diameters apart and located symmetrically with respect to the aircraft centerline (BL 0), and the 36" diameter nose fan. The nose fan is located forward approximately three wing fan diameters on BL=0. For sea level standard day and 100% power conditions at a nominal collective control position, the XV-5A disk loadings for the wing and nose fans are 268 and 274 lb/ft^2, respectively. Fan stream dynamic pressures in theory equal one-half the disk loading, since the fan installation is equivalent to a shrouded propeller. Current ranges of control settings permit differential wing fan disk loadings of ±12.5% by differential stagger, or from 302 to 234 lb/ft^2 full-up to full-down collective stick positions, respectively. The wing fan streams may be collective vectored from approximately -5° to 50° aft and differentially vectored by as much as ±16°.

Using these data and generalized correlations of Kuhn and others, realistic estimates can be made of (1) ground erosion (one type of aircraft signature), (2) particle transport rates, (3) water and dust cloud heights (another type of aircraft signature), (4) particle impingement or terminal velocities, (5) integrated downwash wind velocities, (6) effects on parked aircraft or adjacent field stores, and other practical aspects of downwash phenomena which would be encountered during XV-5A or similar aircraft operational evaluations under simulated or actual field conditions. To date, analysis of the XV-5A in this regard has been limited only to evaluation of the flow field patterns along the ground plane and beneath the fuselage. Figures 5.7 through 5.12 show the estimated zones of interaction between downwash from the wing and nose fans for the aircraft control conditions shown on Table 5-2. Effects of fan stream vectoring are not considered for reasons already stated. The pitch control effects are accounted for by assuming constant fan stream dynamic pressure, and by converting the nonintercepted fan stream area to a conventional hydraulic diameter which replaces the fan diameter for entering the general correlations of Figure 5.3. The valid region of consideration for these studies is estimated to be within a one-foot thick layer in contact with the ground plane.

As a base for comparison, Figure 5.7 shows the fan stream interaction zones with controls in the neutral position. Figures 5.7 and 5.8 show that for the full pitch-up control position, the nose fan-wing fan interaction zone is broadened and forced aft about 24 inches from Sta. 112 to Sta. 136 (vectoring the main fan streams aft would permit movement of

the interaction zone still further aft). For the full pitch-down control position (not shown), none of the nose fan stream touches the ground; thus there is no interaction zone for the nose and wing fan streams, and the interaction zone between the main fans lies along BL=0.

Figures 5.8-5.10 show collective lift has a small effect on the interaction zone locations. Figures 5.11 and 5.12 show the characteristic displacement and distortion effect of ±5% and ±12.5% differential wing fan lift, respectively. The interaction zone line of Figure 5.12 near the wing fans is open to question, because radial ground flow from the weaker fan (right hand wing fan) probably has not had time to develop.

As discussed previously the major effects of fan stream vectoring are the displacement of the impingement center, a strengthening of radial flow in the direction of vectoring, and a weakening of radial flow in the direction opposite to vectoring. Thus, during collective louver vectoring from -10° to 45°, the stagnation zone, say of Figure 5.7, should move aft toward the wing fans and may even move under the wing. Differential vectoring on the other hand should skew the interaction zone as suggested in Figure 5.4(e); thus, a right yaw would tend to skew and rotate the interaction zone counterclockwise, and a left yaw clockwise.

Comparison in Figure 5.13 of the far field flow according to Hess (Reference 5) with the near field flow according to Kuhn (the method followed here) shows the agreement to be relatively good.

With these interaction zone patterns in mind, the general ground flow characteristics can be assessed qualitatively. Figure 5.14 shows a number of zones of interest during static hovering in ground effect. At the interaction zones represented by A and D, a strong upwash is expected which will strike the fuselage bottom. In zones B, C, and E, the streams are expected to be running more or less parallel to the ground plane and to the interaction zone. In zones G and H, the streams are expected to run parallel to the ground plane and more or less radial from their respective sources. On the bottom of the fuselage above zone A, the flow will split, a part moving forward and the remainder aft. The same tendency is expected in zone D, except that only lateral flow is permitted. There is a possibility of flow attachment to the fuselage with resultant upward turning.

In view of the above, one can visualize a number of downwash effects on the XV-5A aircraft and its operation. For example, the lower fuselage will be exposed to warm gases from 220° F to perhaps 400° F. Hot gases from zone D of Figure 5.14 may be ingested by the cockpit, engine and

cooling fans. Likewise, hot gases from zone C, and zone D, may be reingested by the wing and pitch fans. Although the severity of the problem is unknown and may lend itself to correction, it does occur and the ingestion of warm gases will cause decreased gas generator performance, increased fan speeds with reduction in lift, and increased temperature levels for all aircraft items requiring cooling air. Since dust and debris can be carried easily by these intensely acting streams, problems inherent to particle ingestion may also become important - problems such as foreign object damage, maintenance, visibility, aircraft signature, etc.

The purposes of Section 5.3 have been to provide some insight to the varied and complex nature of the XV-5A environment during fan mode operation; to demonstrate the importance of early consideration of downwash phenomena in subsequent aircraft design; and to demonstrate availability of an approximate method to obtain quantitative estimates of particular and practical downwash characteristics for the XV-5A aircraft.

It is recommended that the downwash evaluation be continued beyond that presented here, that the preliminary results be checked against experimental measurements on the XV-5A aircraft, that further general experimental data be gathered on the interaction of multiple streams on triangular spacings, and that experimental data be obtained to permit generalized correlations for vectored fan streams.

5.3.5 Environmental Temperatures

5.3.5.1 Data Sources

As discussed in the previous sections, the local aircraft environment is extremely varied. Local temperatures vary from the 1040° F fan tip turbine exhaust gases to ambient temperature. This section brings together in one place those applicable data gathered from various sources, but principally from high wing VTOL transport tests and full scale XV-5A Model tests conducted in the NASA-Ames 40' x 80' wind tunnel.

5.3.5.2 Data Correlation

Steady state gas and structural temperatures are conveniently correlated by the non-dimensional temperature difference ratio:

$$X_t = (t_m - t_{AMB})/(t_{5.1} - t_{AMB}) = (t_m - t_{AMB})/(EGT - t_{AMB})$$

where t_m is the measured gas or structural temperature, $t_{5.1}$ is the X353-5B gas generator exhaust gas temperature otherwise known or

referred to as EGT, and t_{AMB} is the ambient temperature unaffected by the aircraft. The general validity of this correlation is demonstrated by Figure 5.15 which is based on the data of Table 5.3 and Figure 5.16. In spite of its general validity, it has some inherent discrepancies, (e.g. external gas temperatures controlled by fan turbine exhaust gases should be based on fan turbine exhaust gas temperature rather than $t_{5.1}$, and the ambient temperature should be the local environmental temperature as affected by downwash phenomena rather than "Weather Bureau" ambient temperatures). Again, there is always the temptation to use this correlating ratio for transient data. As long as events are the same and changes are relatively slow, the ratio may be used as a reasonable approximation, however, where conditions change rapidly (e.g. EGT as a function of a step change in gas generator RPM) changes in the value of X_t can be misleading, and its use can produce erroneous conclusions.

5.3.5.3 Lower Fuselage

The data presented in Figures 5.17 through 5.21, represent estimates of external gas isotherms washing the fuselage sides below the wing from Station 150 to 350 for typical conditions of power setting, wing fan stream vector angle and aircraft speed. The region covered includes most of the titanium center fuselage lower access section and the main landing gear cavity. The isotherms are based on NASA-Ames Test 177 Run 16 data and correlated test results on the high wing transport model. Not directly applicable to the XV-5A, these data were treated as follows:

1. The high wing transport data were recorrelated in terms of vertical distances from the lift fan rotational plane expressed as fan diameters (Y/D).

2. It was assumed vectoring would deflect all data points through the same angle from their point of origin in the fan plane.

3. It was assumed for forward flight that the resultant fan stream vector would be equal to the vector sum of vectored fan stream and flight (or free stream) velocities.

4. Values of fan turbine exhaust gas temperatures were taken from Figure 5.16 at the selected gas generator speeds.

5. Based on flap effectiveness data, it was assumed hot gases would be pulled through the wing trailing edge slot when the flap was set at an angle of 45 degrees.

Comparison of Figures 5.17 through 5.21 shows maximum severity of exposure forward of the wing fan center occurs at maximum power (100% J85 RPM), 0 to 10° fan stream vector, with the aircraft on the ground (tie-down test, Figure 5.19); while maximum severity aft of the wing fan center occurs at 100% J85 RPM, fan stream vectoring to 50°, and a flight speed of 100 knots, Figure 5.21. Although the latter data were taken essentially out of ground effect ($h/D > 3.0$), they are considered applicable to ground runs ($h/D = 1.0$) as well.

In close proximity to the ground (h/D from 1.0 to 2.0), powered fan model data revealed positive pressure coefficients along the fuselage bottom when operating in the fan mode. Combined with these data, cooling system performance analysis shows pressure differences tending to promote external hot gas leakage into the fuselage. A similar condition appears to exist at the wing root near the fan louvers which is relatively independent of ground proximity. Thus, in these regions, leakage through unsealed skin joints or access panel closures can be expected.

5.3.5.4 Landing Gear

A need for detailed knowledge of the downwash phenomena, particularly the fan stream flow field, both out of ground effect and in the ground impingement region, was required for design of the XV-5A landing gear. Data was required defining the hot gas sheath location under various combinations of collective and differential vectoring and staggering. The lattice array of thermocouples shown in Figures 5.22 and 5.23 (for reference see also Figure 2.4) was installed on the full scale XV-5A Model in the NASA-Ames 40' x 80' wind tunnel for Runs 11, 18, and 21 of NASA-Ames Test 177. Selected raw data from these runs are presented in Table 5-4 and plotted in Figures 5.24 through 5.28. (Note: The data of Table 5-4 were prepared from original data according to the procedure of Reference 6, Note 2; except that the ΔT correction factor of Note 1 was not used; because by its use many results would have been substantially below tunnel ambient temperatures and unrealistic.)

Figure 5.29 provides a convenient method for converting temperatures measured at any given ambient temperature and 86% J85 RPM to maximum estimated temperatures at 100% J85 RPM and 100° F ambient temperature. As an aid to interpreting the wind tunnel test results, estimates of the fan tip turbine exhaust gas location and temperature decay rates were made based on information from References 4 and 6-9. Figure 5.30 shows a comparison of estimated and measured tip turbine exhaust gas temperature decay with distance from the louvers assuming the turbine blade width as the characteristic dimension. By comparison it

appears the tip turbine exhaust gases cool more rapidly at first, and then more slowly than predicted. A partial explanation may be initial intermixing as the two streams join to form a stream of larger effective characteristic dimension. Figures 5.31 and 5.32 show estimated outer boundaries of the main wing fan streams at vector settings from -12 to 45° for aircraft heights of h/D = 1.0 and h/D = 1.7, respectively, at the fan centerline (BL = 61) for static conditions on a calm day (no wind). These outer boundaries act as the interface between the "sheath" of hot turbine gases and the cold fan stream. In forward flight or in the presence of an equivalent head wind, these estimated boundaries may be rotated still further aft some incremental amount as suggested in Figure 5.33.

When more or less out of ground effect, the apparent turning angle (based on data of Tables 5-4 through 5-6) falls about midway between the louver angle and the resultant velocity angle (Table 5-7) obtained by vector addition of the fan stream and wind or aircraft velocities. In ground effect (h/D = 1.0) the apparent turning angle is much greater as one would expect due to fan stream turning. Data of Table 5-4 at h/D = 1.7 also suggests a higher turning angle with increasing aircraft or tunnel velocities, as indicated by the low temperatures of the entire thermocouple lattice array at 80 knots compared to 40 knots.

The action suggested is that the fan and turbine streams act as large cylindrical fluid columns which offer considerable blockage to the free stream flow; and are, therefore, under certain conditions turned significantly by the free stream flow. At zero vectoring in strong ground effect (h/D = 1.0), any free stream air flow between the two wing fan streams is largely blocked by downwash phenomena previously discussed; however, as vectoring aft is increased, the resistance to such flow is decreased. The flow around the fan streams, particularly out of ground effect, may account for some of the underwing temperature distributions to be discussed in the next section.

Referring to the main landing gear and its diagonal supporting structure (see Figure 2.3), it is evident that some parts of it will be exposed to hot tip turbine gases in nearly all conditions of fan mode operation in or out of ground effect. The estimated maximum exposure temperature determined from Table 5-4 and Figure 5.29 is 735° F obtained by the summation of 547° F from Run 18, Point 20 of Table 5-4 and Δt_M = 188 from Figure 5.29. Based on the method of prediction in Figure 5.30, the estimated maximum temperature would be approximately 900° F. The higher value of 900° F has been used as a basis for design of landing gear

protection systems. Similar conditions are expected for the main wheel well and its doors at louver vector settings above 15° to 20° F.

5.3.5.5 Wing and Flap Surface

Much of the discussion in the previous sections has a direct or indirect bearing on the wings and flaps. A general survey of wing and flap surface temperatures was made during NASA-Ames Test 177 Run 16 (see Section 9.6.6) using Pyrodyne Template indicators. The results showed considerable heating even with the aircraft at an h/D = 2.2 and at tunnel speeds from 30 to 60 knots. The environments of the lower wing surface at the rear spar, and the flap surfaces were investigated for several runs by the series of thermocouples presented in Figure 5.34. As an aid to interpreting and assessing applicability of the test results, recall that during ground tie-down and wind tunnel tests almost any combination of vectoring, aircraft velocity, and power setting can be established. On the other hand, in fan mode flight the range of operating conditions is relatively restricted as indicated by the trimmed flight corridor of Figure 5.35. However even in this corridor, by a combination of power settings and angles of attack, a substantial range of vector angles is permitted at a given trimmed flight velocity. During sustained fan mode flight and generally during fan mode accelerations to conventional mode transition, the aircraft controls must be within the typical corridor as indicated. For the reverse operation (return to fan mode from conventional mode flight), trimmed flight conditions are not required, and untrimmed flight conditions may be maintained, until actual VTOL landing procedures are initiated. Of course, fan mode flight in the untrimmed condition is inherently transitory and of relatively short duration.

There are a number of possible mechanisms which can take part in establishing high temperature environments over the wing and flap surfaces:

(1) direct impingement due to lateral spillage from the louver tips (this should increase with increasing stagger),

(2) direct impingement due to partial reverse vectoring of the turbine exhaust gases when they strike the exit louvers as suggested by sketches (A) and (B) of Figure 5.36 (a form of downwash phenomena),

(3) flap action, particularly at high louver angle settings,

(4) upwash from beneath the fuselage in ground effect at low louver angles.

(5) shearing action and eddy formation due to relative wind velocities (aircraft or tunnel velocities) normal to and around the cylindrical fan downwash,

(6) attachment of turbine exhaust gases to the fuselage walls followed by subsequent detachment at high louver angles,

(7) at high angles of attack there is some evidence of a stagnation region developing in the fan stream (somewhat analagous to that experienced when the fan stream strikes the ground plane) so that some of the turbine exhaust gases are split off the main stream to flow forward along the lower wing surface, around the leading edge, and across the upper wing surface to be drawn into the wing fan,

(8) development of general recirculation patterns during static fan mode operation in ground effect. This effect can be affected strongly by prevailing winds.

The first seven items are applicable to the lower wing and flap surfaces, while items 3, 7, and 8 are applicable to the upper wing and flap surfaces. It is doubtful that any single mechanism accounts for the high temperatures observed. More likely various and different combinations of these and/or other mechanisms become effective as the aircraft moves through its wide range of possible operating conditions of power setting, angle of attack, aircraft or tunnel velocity, altitude, pitch control fan modulations, and wing fan louver vector and/or stagger angles including both collective and differential settings.

Upper Wing Surface Environment

Experimental data from NASA-Ames Test 177 Run 16 (see Section 9.6.6) shows upper surface temperatures to 250° F. Adjustment to 100% power and hot day conditions indicates a maximum environmental temperature of 340° F.

Upper Flap Surface Environment

Data of Run 16 also shows upper flap surface environmental temperatures at the hinge line to be at least 250° F, and adjusted as above, a maximum

of 340° F. Assuming hot gas flow through the flap gap, the flap at the wing root would be exposed to the environments of Figures 5.17 through 5.21.

Wing Leading Edge Environment

Same as the upper wing surface environment.

Lower Wing and Flap Surface Environment

Data for this region are more complete. Selected data from NASA-Ames Test 177 (see Table 5.8 and Section 9.6.5), are presented in Figures 5.37 through 5.82 which show the effects of aircraft height h/D, fan vector angle setting β_V, aircraft velocity V_p, thrust reverser position R, and aircraft angle of attack α on the lower wing and flap surface environmental temperatures. Figure 5.57 presents a time-temperature profile of the lower surface environment during tie-down ramp tests at power settings of 95% J85 RPM (See Run 56, section 9.6.6). Examination of Figure 5.57 suggests that 1.5 to 2.0 minutes are required to establish stable surface environmental temperatures after diverting from conventional to fan mode. In comparison with Figures 5.43 through 5.54, the data of Figure 5.57 indicates reduced environmental temperatures at the higher power settings, although the marked reductions may be due in part to relative velocity effects. Figures 5.61 through 5.72 show various cross-plots of data. Superimposed on these plots are estimated operating lines for 86% and 100% power operation, based on the trimmed flight conditions (β_V vs V_p) of Figure 5.36. The operating lines were used to develop the environmental isotherms of Figures 5.83 through 5.88 which are representative estimates for fan mode operation out of ground effect.

For tie-down tests and for lift-off conditions, the data of Figure 5.57 apply directly. For static hovering out of ground effect, it is estimated the lower wing and flap surface environment will approximate 200° F based on Figures 5.57, 5.59 and 5.60. Figures 5.59 and 5.60 show a general decrease of environmental temperature with increasing aircraft height (h/D) as one might expect. The dashed operating line data of Figures 5.61 through 5.72 were cross-plotted in Figures 5.73 through 5.82 to yield approximate distributions and trends. A linear interpretation was applied to the data at a given station, (e.g. Figures 5.73, 5.74 and 5.75). The station distribution at a given butt line is open to interpretation and depends upon the action assumed to be taking place at the flap. Two opposing assumptions can be made: (1) hot gases are passing upward through the flap gap, or (2) relatively cool gases are being drawn

downward through the gap. If the former assumption is made, the data points can be connected as shown by the V_p = 40 knot line of Figure 5.76. If the latter assumption is made, a low temperature trough exists between Stations 302 and 307 which represent the approximate flat slot width. In this case the data is interpreted as shown by Figure 5.76. Similar treatment is shown in Figures 5.77, 5.81 and 5.82. In Figures 5.81 and 5.82, gases are assumed to be passing upward through the gap at V_p = 100 knots and being drawn downward through the gap for aircraft speeds V_p = 80 or below. Which of these two flap actions occurs can be determined only by test. The assumption of an upward flow is more conservative and leads to underwing isotherms similar to those of Figures 5.86 and 5.87. The assumption of a downward flow leads to underwing isotherms similar to those of Figures 5.83 through 5.85. As mentioned previously, the upward flow (natural flap action) concept was adopted and used to determine insulation requirements. Its use required insulation of the fuselage at the wing root (see Figure 6.4) and the aft fairing (see Figure 6.5). Also, it required replacement of the aluminum flap with titanium inboard of BL 61.

TABLE 5-1

Definition of Terms

Term	Definition
Vector	Deflection of fan stream by means of exit louvers
Collective Vector	Both wing fan streams are vectored through the same angle
Differential Vector	The separate fan streams are vectored in opposite directions from the collective vector position. (Note: differential vectoring is superimposed on the collective vector position. Generally individual fan streams are vectored through the same angle except where limited by stops.)
Stagger	Odd numbered and even numbered louvers are moved toward the other to "pinch" the flow as a form of area control to vary the fan lift.
Collective Stagger	Both wing fan streams are "pinched" the same amount.
Differential Stagger	The separate fan streams are differentially "pinched" from the collective stagger position.
Thrust Reverse	This term is reserved for control of nose fan lift. Curvelinear thrust reverser doors are designed to intercept equal segments of the nose fan stream and to deflect them outward. The amount of thrust reversal depends upon the degree of fan stream interception. Full, or maximum, thrust reversal occurs with complete interception of the nose fan stream.
Thrust Spoiler	This term is reserved for the turbojet mode exhaust gases. The exhaust gases are deflected symmetrically outward by turning vanes which are inserted into the turbojet exhaust.

TABLE 5-1 (Continued)

Term	Definition
Downwash Phenomena	A general term relating to any action or result that can be traced back to flow fields developed around the aircraft when operating in the fan mode.
Downwash	Refers to the fan stream flow path from the time it leaves the fan. In ground effect it includes impingement on the ground, fan stream turning, and the radial outflow along the ground from the effective impingement center.
Interaction Zone	That region between fan streams where opposing ground running streams encounter each other. It is assumed no net flow crosses this region.
Ground Plane	Refers to a relatively thin layer within one to one and one-half feet of the ground surface.
Upwash	Generally vertically upward flow.
Ground Flow	Flow parallel to and along the ground plane.

TABLE 5-2

Aircraft Operating Conditions* Used For Estimating XV-5A Downwash Interaction Zone Locations

	Control Positions				Estimated Stagnation Point	
			Differential Lift			
Figure	Pitch Control	Collective Lift	Left Fan	Right Fan	BL	STA.
5.7	Neutral	Neutral	None		0	112
5.8	Full Up	Neutral	None		0	136
5.9	Full Up	Full Down	None		0	140
5.10	Full Up	Full Up	None		0	134
5.11	Full Up	Neutral	+5%	-5%	6	136
5.12	Full Up	Neutral	+12.5%	-12.5%	15	135

*ARDC Standard Day, Sea Level 100% J85 RPM

TABLE 5-3

Correlation of Measured Temperature Data °F
Reference Data: NASA-Ames Run 61 Test 177

Rdg.	% J85 RPM	N_{FL} RPM	$t_{5.1}$ (Meas.)	$t_{5.1}$ (Fig. 5-4)	Thermocouples 6	16	17	18	19	20	21	t_{AMB}
1	78	1430	968	850	228	246	214	294	56	108	216	46
2	85	1700	968	950	248	268	224	328	62	120	236	46
3	94	2320	1112	1140	262	296	250	358	60	130	258	46
4	94	2350	1112	1140	248	266	218	374	100	142	258	46

TABLE 5-4

Selected Data for Landing Gear Environ

Run	Point	V_p Knots	t_o °F	N_p RPM	N_{FL} RPM	N_{FR} RPM	h/D	δ_F Degrees	R Degrees	β_V Degrees	1	2
11	14	40	80	0	1700	1720	1.7	45	-	-12	386	39
	13	40	78	0	1750	1750	1.7	45	-	0	262	38
	12	40	77	0	1700	1700	1.7	45	-	15	332	28
	11	40	76	0	1710	1710	1.7	45	-	30	210	27
	2	40	66	0	1710	1700	1.7	45	-	35	66	15
	9	40	74	0	1720	1690	1.7	45	-	40	90	8
	10	40	75	0	1720	1740	1.7	45	-	50	76	7
	16	80	82	0	1720	1700	1.7	45	-	35	80	8
	23			0	1720	1700	1.7	45	-	40	80	8
	24			0	1750	1730	1.7	45	-	50	82	8
18	25	20	85	2350	1680	1730	1.0	45	0	20	130	41
	2	30	63	2400	1700	1710	1.0	45	0	20	103	37
	9	40	76	2400	1700	1690	1.0	45	0	20	132	4
	17	60	82	2400	1700	1680	1.0	45	0	20	132	4
	1	30	61	2400	1710	1690	1.0	45	0	0	98	4
	9	40	76	2400	1700	1690	1.0	45	0	20	132	4
	10	40	78	2400	1700	1710	1.0	45	30	20	135	3
	11	40	78	2375	1710	1700	1.0	45	45	20	133	3
	13	40	79	2400	1690	1670	1.0	45	60	20	140	4
	12	40	79	2400	1700	1680	1.0	45	70	20	162	4
	17	60	82	2400	1700	1680	1.0	45	0	20	132	4
	18	60	83	2400	1700	1670	1.0	45	30	20	138	4
	19	60	84	2400	1710	1680	1.0	45	45	20	150	4
	21	60	84	2400	1700	1690	1.0	45	60	20	178	4
	20	60	84	2400	1700	1700	1.0	45	70	20	166	4
21	1	30	76	2400	1700	1690	2.2	45	60	15	328	3
	10	40	87	2400	1690	1680	2.2	45	60	22	138	1
	17	60	91	0	1700	1700	2.2	45	60	0	88	

*See Figure 5.22 for thermocouple locations and identification.

A

TABLE 5-4

Landing Gear Environmental Temperature Study

Gas Temperature Thermocouples ° F*

β_V Degrees	1	2	3	4	5	6	7	8	9	10	11	12	13	$(EGT)_L$ ° F	$(EGT)_R$ ° F
-12	386	394	294	302	352	272	134	282	242	142	242	230	-	1076	1094
0	262	384	358	178	258	334	118	110	252	100	102	198	-	968	1040
15	332	282	338	244	222	176	158	92	92	104	96	92	-	968	1004
30	210	272	330	140	178	228	258	170	86	140	188	184	-	968	1004
35	66	150	244	84	84	92	196	260	132	76	74	112	-	968	968
40	90	80	140	82	80	76	186	78	190	74	74	74	-	968	1004
50	76	74	80	74	72	72	178	74	80	72	72	72	-	968	1004
35	80	80	82	80	80	80	80	80	80	80	80	8	-	1040	1040
40	80	80	80	80	80	80	80	80	80	80	80	80	-	932	1004
50	82	81	81	102	81	81	81	81	81	81	108	81	-	932	1004
20	130	412	542	221	150	210	118	100	376	141	126	113	140	950	932
20	103	376	474	200	141	200	90	89	330	96	90	84	98	932	932
20	132	418	500	173	160	232	122	100	364	92	90	91	92	932	932
20	132	436	540	343	174	306	185	102	344	100	100	100	104	932	932
0	98	400	302	90	208	394	91	105	184	94	85	168	91	932	932
20	132	418	500	173	160	232	122	100	364	92	90	91	92	932	932
20	135	373	517	275	170	218	140	100	353	96	97	96	94	932	932
20	133	388	526	222	164	230	120	102	340	107	105	99	106	932	932
20	140	433	518	198	186	245	112	112	352	112	108	106	114	932	932
20	162	428	542	247	213	262	108	113	358	107	106	105	107	932	932
20	132	436	540	343	174	306	185	102	344	100	100	100	104	932	932
20	138	440	533	293	158	302	124	106	340	114	104	106	114	932	932
20	150	456	552	217	198	270	124	118	357	130	116	115	134	932	932
20	178	484	538	341	240	293	120	119	352	116	112	113	126	932	932
20	166	464	547	333	212	289	110	114	352	110	106	106	122	932	932
15	328	354	310	-	-	-	-	-	-	-	-	-	-	932	932
22	138	152	234	-	-	-	-	-	-	-	-	-	-	932	932
0	88	88	88	-	-	-	-	-	-	-	-	-	-	932	932

B

TABLE 5-5

Angle from Fan Turbine Exhaust Outlet to Thermocouples of Main Landing Gear Lattice

Plane Through BL = 31

	FORWARD TURBINE						AFT TURBINE					
h/D	TC1	2	3	4	5	6	1	2	3	4	5	6
1.0	55	64	70	38	48	56	-5	29	51	-4	17	34
1.7	27	36	43	21	29	36	-2	11	23	-2	8	18
2.2	19	26	33	16	22	28	-1	7	16	-1	6	13

Plane Through BL = 51

	FORWARD TURBINE						AFT TURBINE					
h/D	TC7	8	9	10	11	12	7	8	9	10	11	12
1.0	65	70	74	48	55	59	-38	-8	27	-23	-4	15
1.7	35	43	49	29	36	42	-15	-2	10	-12	-1	7
2.2	25	32	38	22	28	33	-11	-2	6	-9	-1	5

TABLE 5-6

Apparent Turning Angle of Fan Turbine Exhaust β_{AP} (Based on Main Landing Gear Lattice Array)

			Plane Through BL = 31					Plane Through BL = 51				
			TOP ROW		BOTTOM ROW			TOP ROW		BOTTOM ROW		
h/D	V_p	β_v	TC_{max}	β_{AP}	Source*	TC_{max}	β_{AP}	TC_{max}	β_{AP}	Source*	TC_{max}	β_{AP}
1.0	20	20	3	51	A	--	--	9	27	A	--	--
	30	20	>3	--	A	--	--	--	--	-	--	--
	40	20	<3	--	A	--	--	--	--	-	--	--
	60	20	3	70	A	--	--	--	--	-	--	--
	30	0	2	29	A	6	34	9	27	A	12	15
1.7	40	-12	1	-2	A	5	8	8	-2	A	11	-1
		0	2	11	A	6	18	9	10	A	12	7
		15	1,3	27,23	FA	4	27	<7	<35	F	<10	<29
		30	3	43	F	6	43	7	35	F	11	36
		35	>3	>43	F	--	--	8	43	F	>12	>42
		40	-	--	-	--	--	9	49	F	--	--
		50	-	--	-	--	--	>9	>49	F	--	--
2.2	60	0	-	--	-	--	--	--	--	-	--	--
	30	15	2	26	F	--	--	--	--	-	--	--
	40	22	3	33	F	--	--	--	--	-	--	--

*Source: A = aft inboard quadrant; F = fwd inboard quadrant

TABLE 5-7

Resultant Vector Angle Vs Aircraft Velocity* and Louver Angle (β_V)

β_V	$V_p = 0$	10	20	30	40	60	80	100 Knots
-15	-15	-10.2	-5.3	-.3	4.7	14.4	23.3	31.2
-10	-10	-5.2	-.3	4.6	9.5	18.7	27.0	34.3
0	0	4.8	9.6	14.2	18.7	26.9	34.0	40.2
10	10	14.7	19.2	23.4	27.5	34.6	40.8	45.9
20	20	24.4	28.5	32.4	35.9	42.1	47.3	51.6
30	30	34.0	37.6	41.0	44.1	49.3	53.6	57.2
40	40	43.5	46.7	49.5	52.0	56.3	59.9	62.7
45	45	48.2	51.1	53.6	55.9	59.8	62.9	65.5

*Assumed Fan Stream Speed = 200 ft/sec at an angle of β_V

TABLE 5-8

Under Wing and Flap Environment: Temperature Data Sources
(See Ames Test Data Section 9.6.)

Figure No.	Run	V_p	h/D	α	β_v	N_p	N_F	t_{AMB}	δ_F	R	Time
5.37	11	30	1.7	0	~	0	1700	60	45	-	-
5.38		40		0	~						
5.39		40		~	35						
5.40		60		0	~						
5.41		80		0	~						
5.42		80		~	35						
5.43	18	30	1.0	0	20	2400	1700	60	45	~	
5.44		40								~	
5.45		60								~	
5.46		~		0						0	
5.47		30		~						60	
5.48		40		~						60	
5.49		60		~							
5.50	41	30	1.0	0	~	2400	1700	60	45	60	
5.51		60			~						
5.52	19	30		~	20	1800	1400	60	45	45	
5.53		40		~	32	1600	1200			60	
5.54		50		~	45						
5.55	16	30	2.2	0	0	2400	1700	60	45	~	
5.56				~	0					45	
5.57	56	0	1.0	0	±5	4000	2400			0	~
5.58											Iso-therms
5.59	~	30	~	0	0						
5.60	~		~		20						

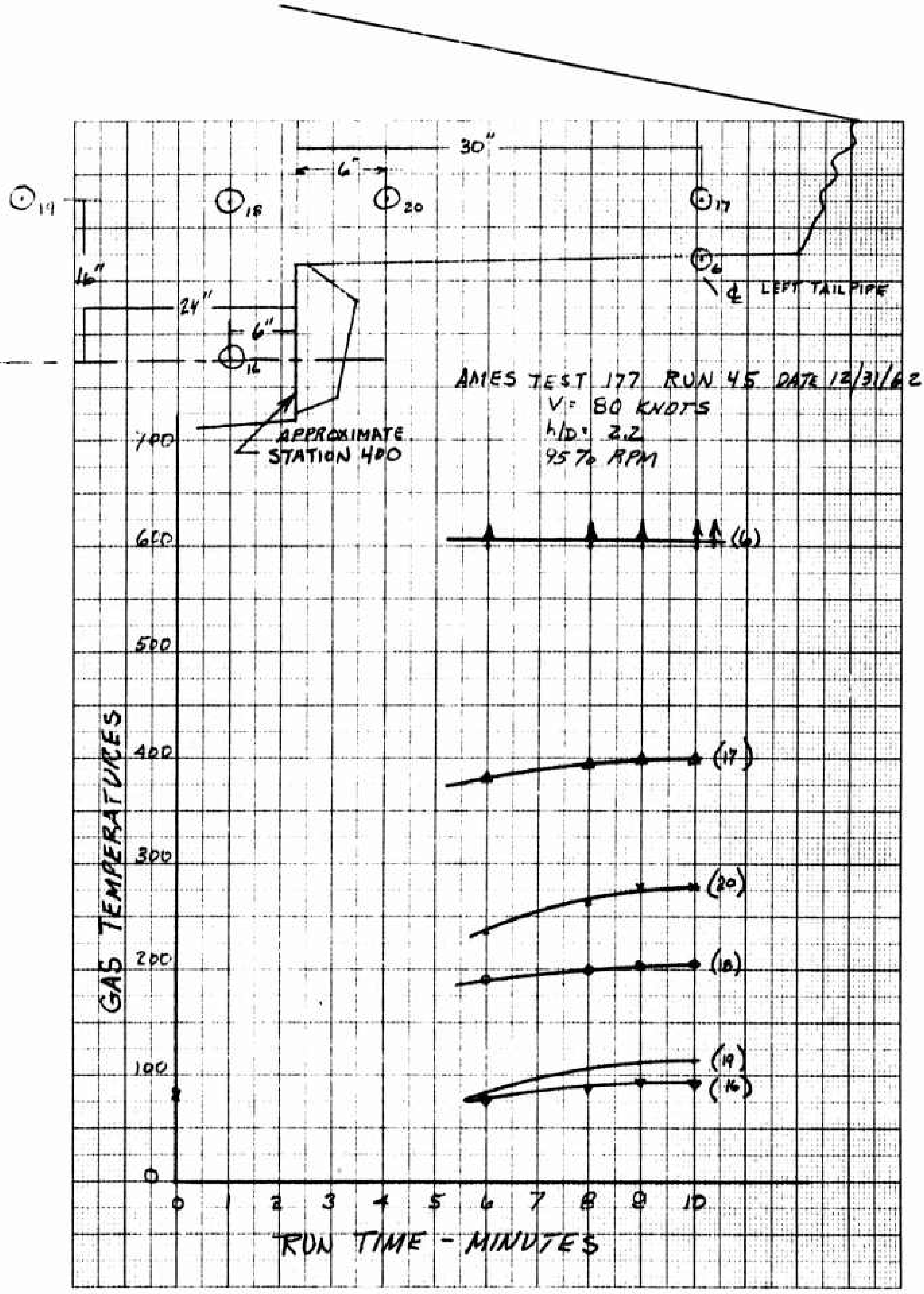
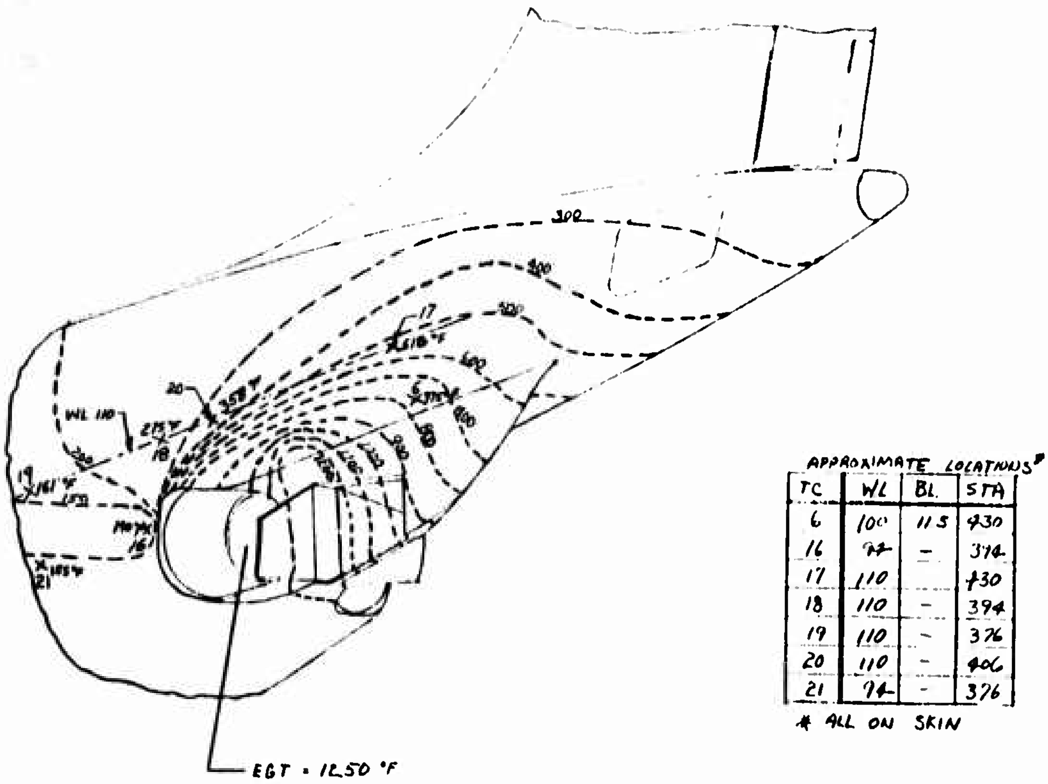


Figure 5.1 Aft Fuselage Temperatures During Thrust Spoiler Operation

RYAN 64B017



TC	WL	BL	STA
6	100	115	430
16	94	-	374
17	110		430
18	110	-	394
19	110	-	376
20	110	-	406
21	94	-	376

APPROXIMATE LOCATIONS*

* ALL ON SKIN

Figure 5.2 Estimated Isotherms During Thrust Spoiler Operation

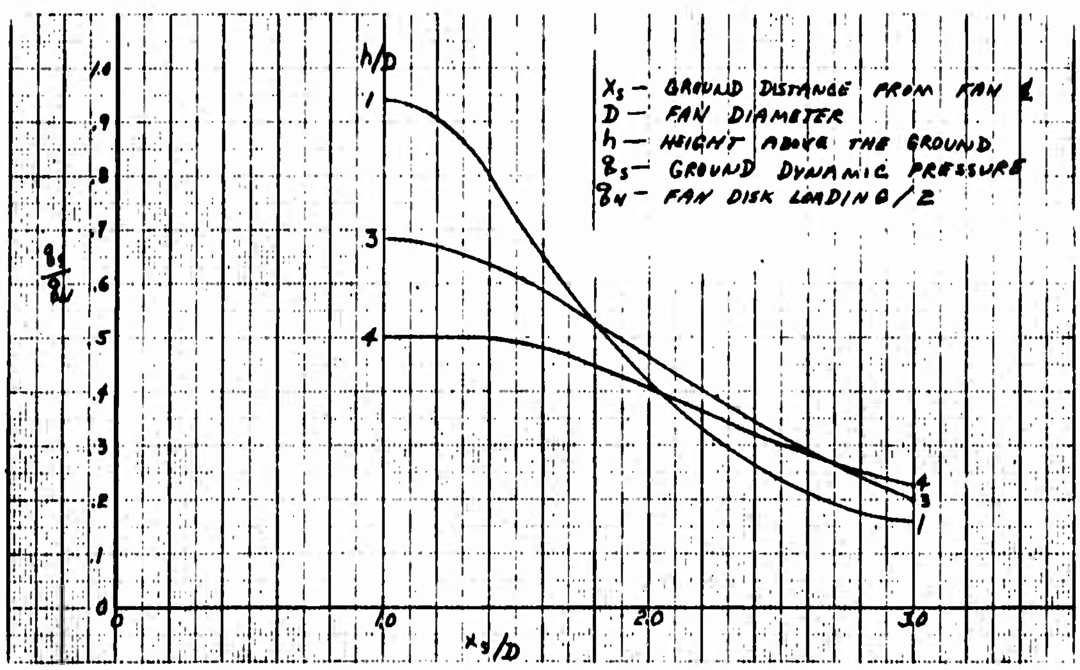


Figure 5.3 Generalized Correlation of Downwash Ground Flow vs Distance and Height

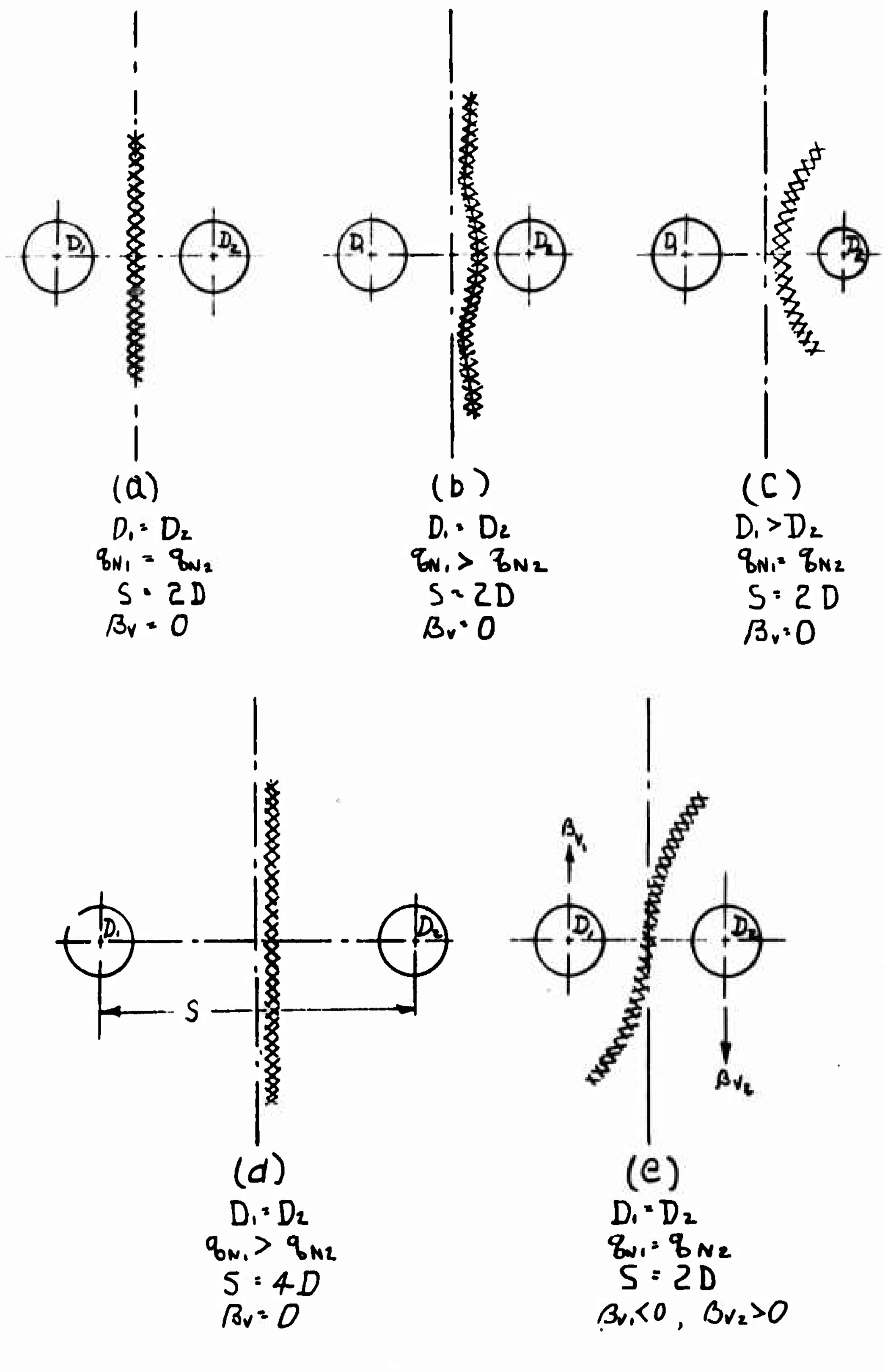


Figure 5.4 Typical Interaction Zones Between Two Fan Downwash Streams

RYAN 64B017

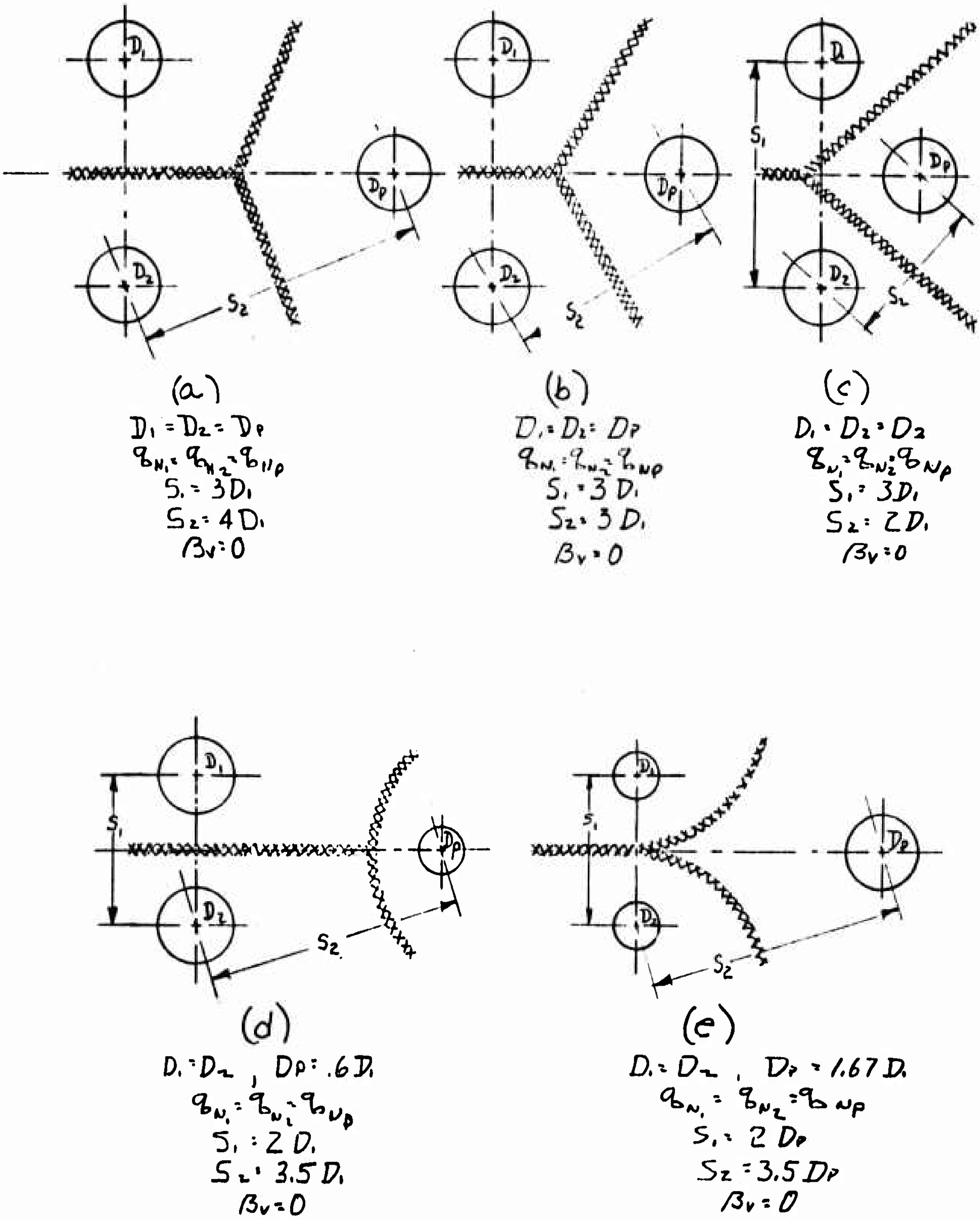


Figure 5.5(a) Typical Interaction Zones Between Three Fan Downwash Streams

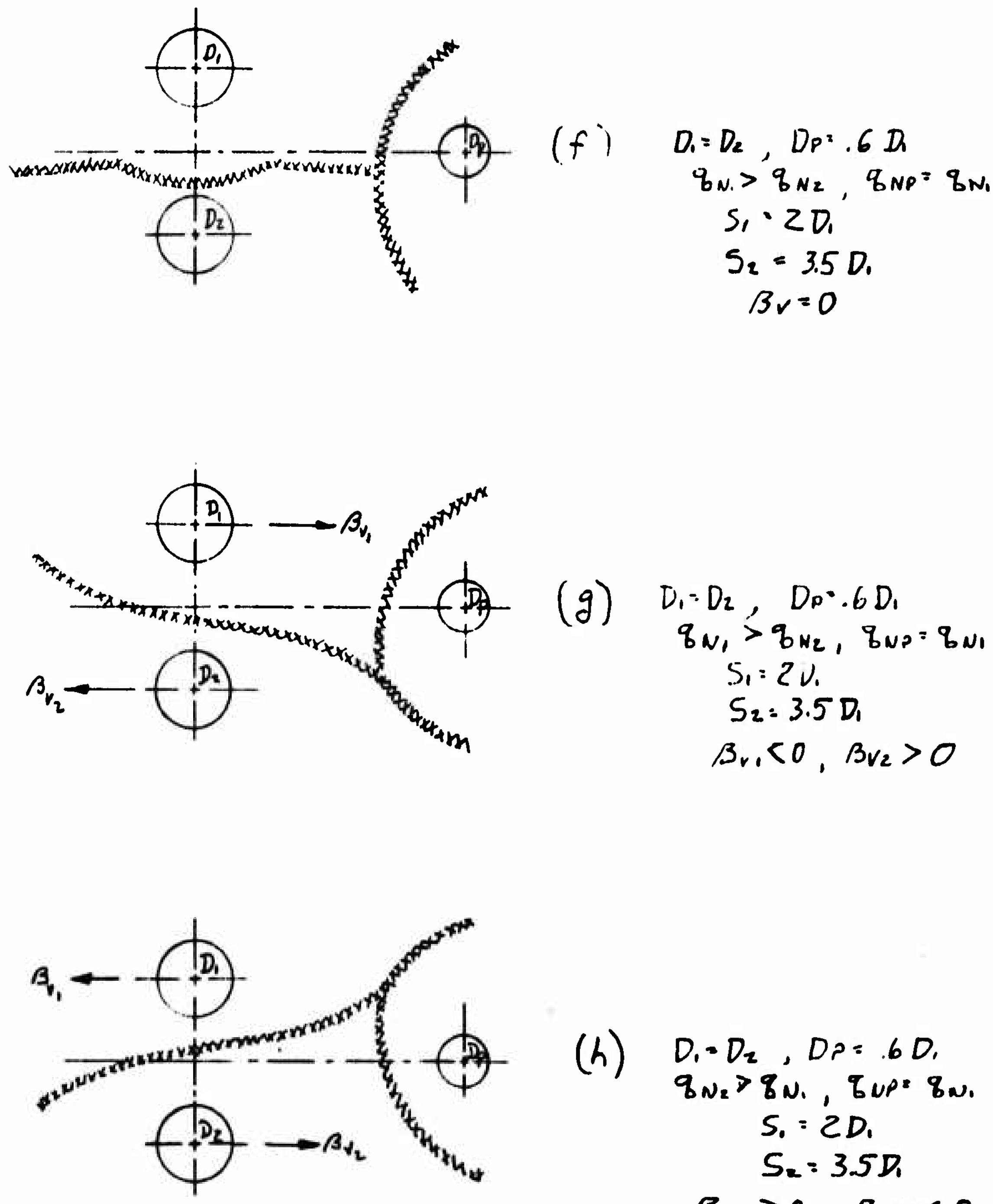


Figure 5.5(b) Typical Interaction Zones Between Three Fan Downwash Streams

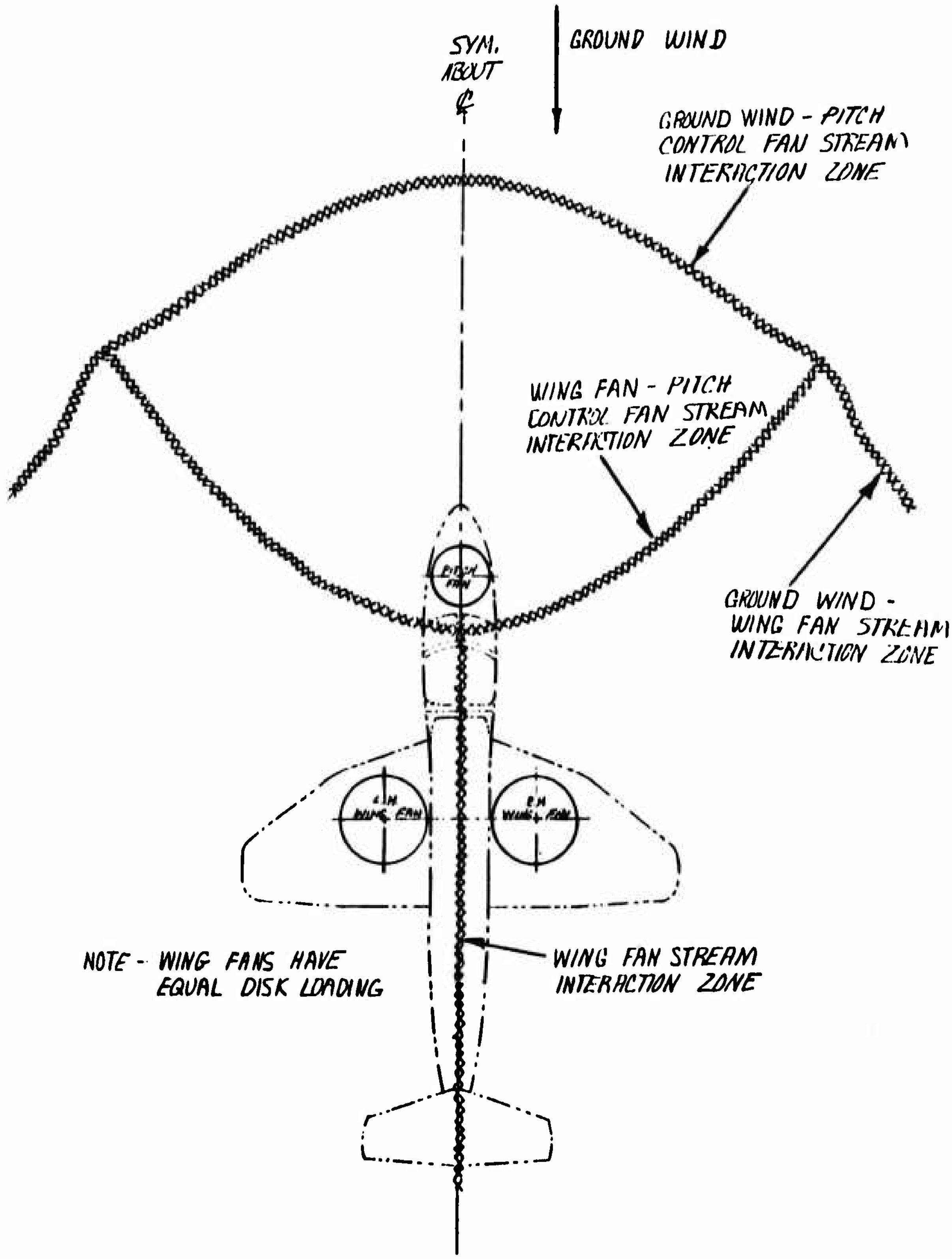


Figure 5.6 **Representative Interaction Zone Between a Head Wind and Aircraft Downwash**

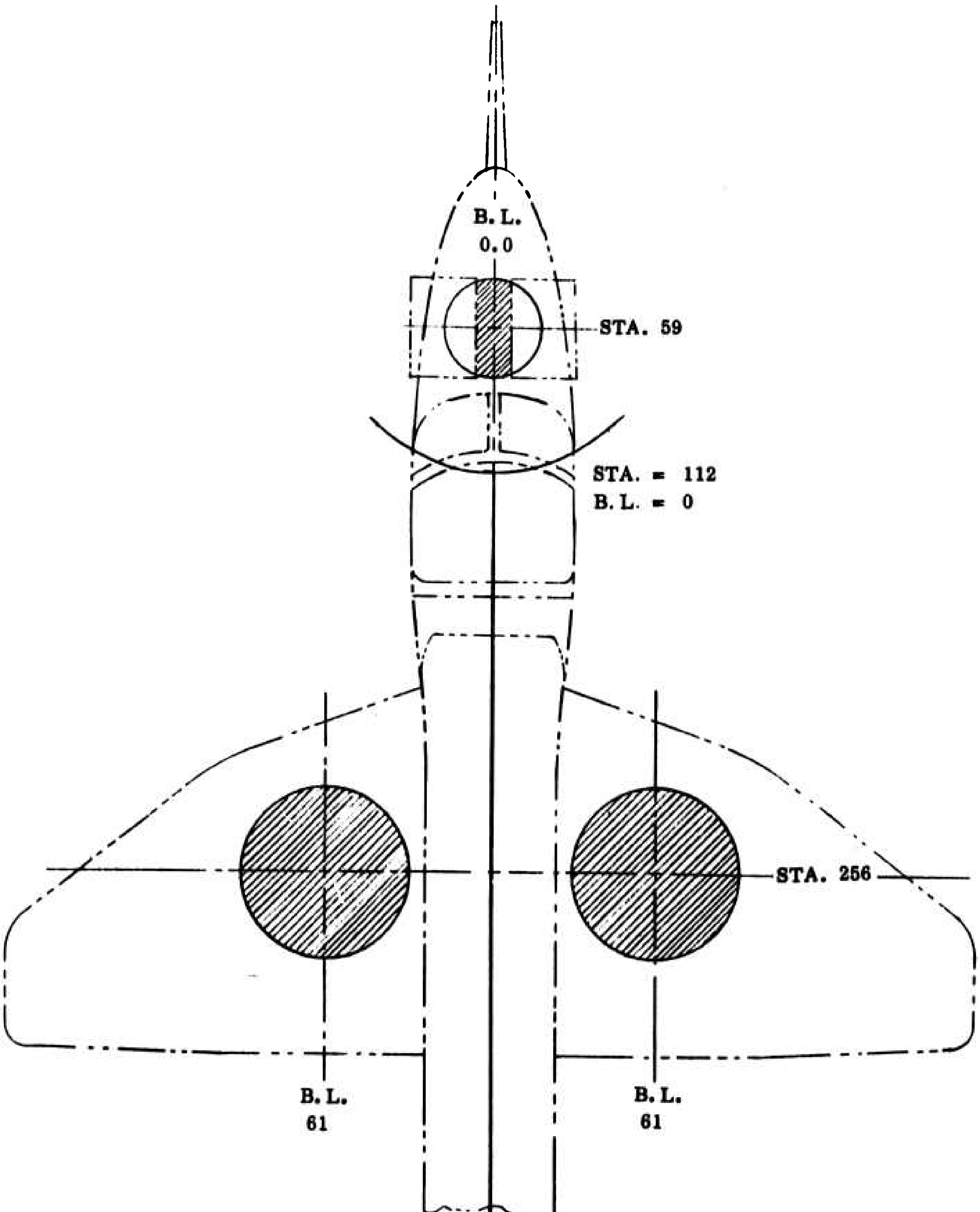


Figure 5.7 Estimated XV-5A Interaction Zones - Aircraft Controls at Neutral Collective and Neutral Pitch Up Positions

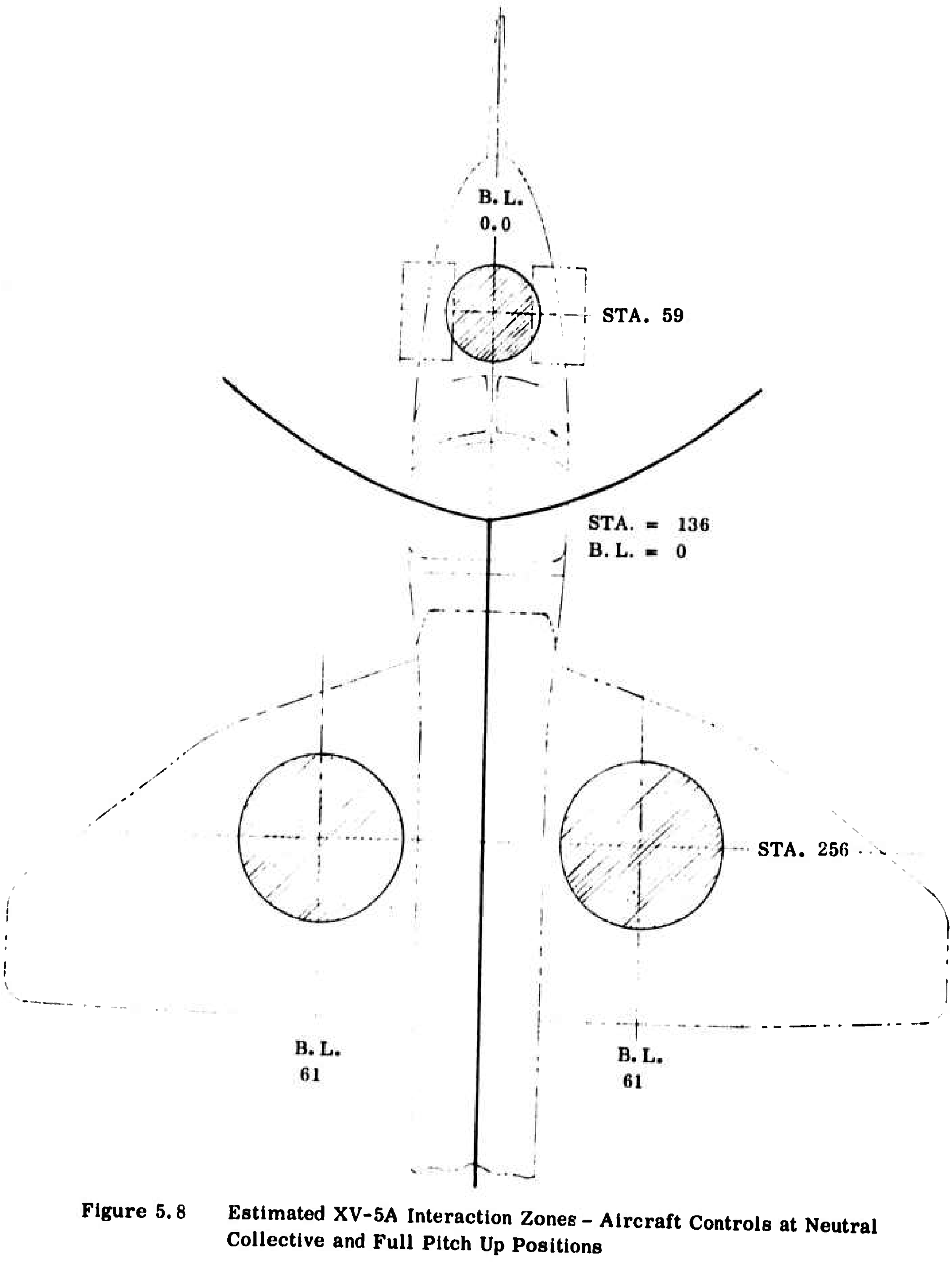


Figure 5.8 Estimated XV-5A Interaction Zones - Aircraft Controls at Neutral Collective and Full Pitch Up Positions

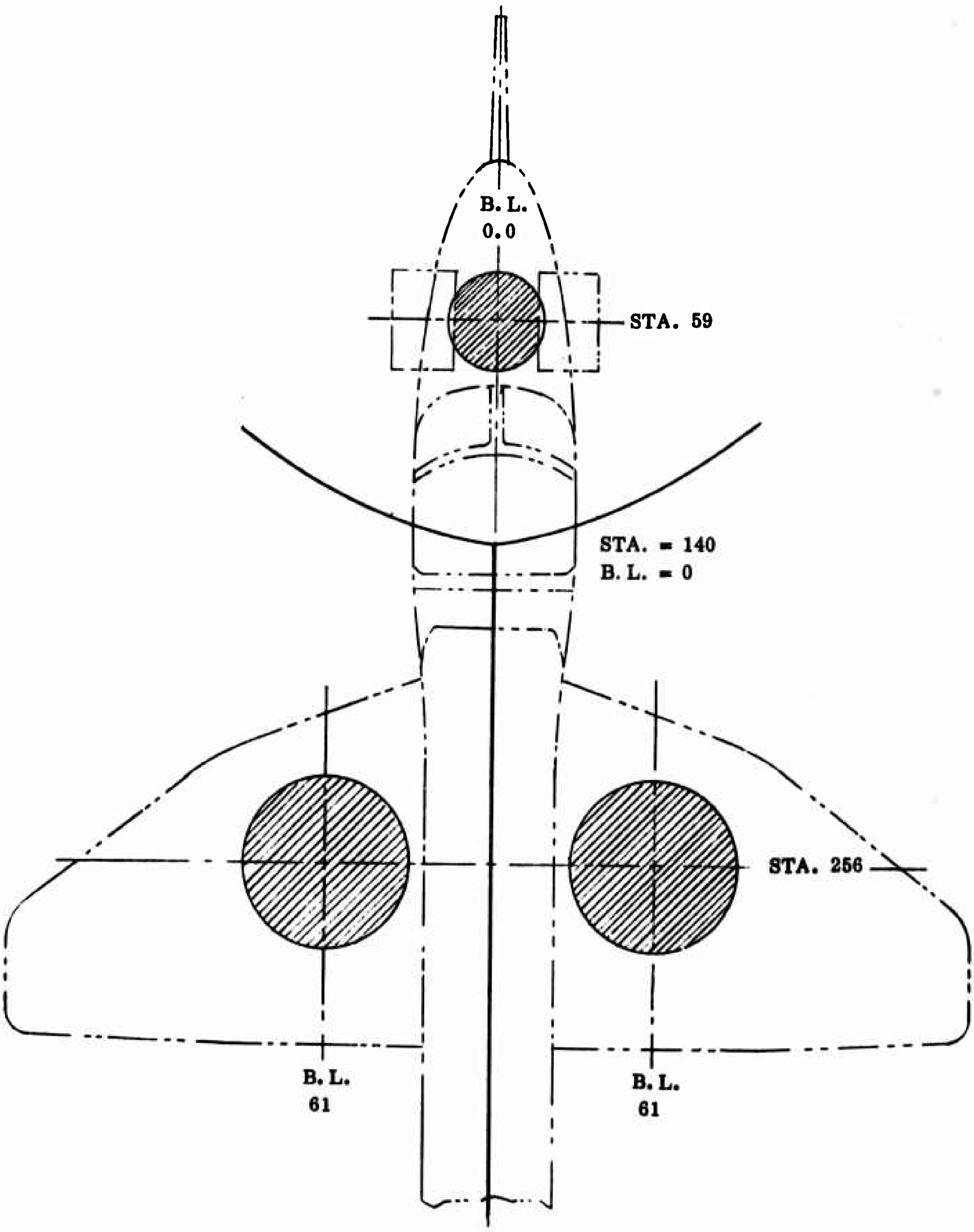


Figure 5.9 **Estimated XV-5A Interaction – Zones – Aircraft Controls at Full Down Collective and Full Pitch Up Positions**

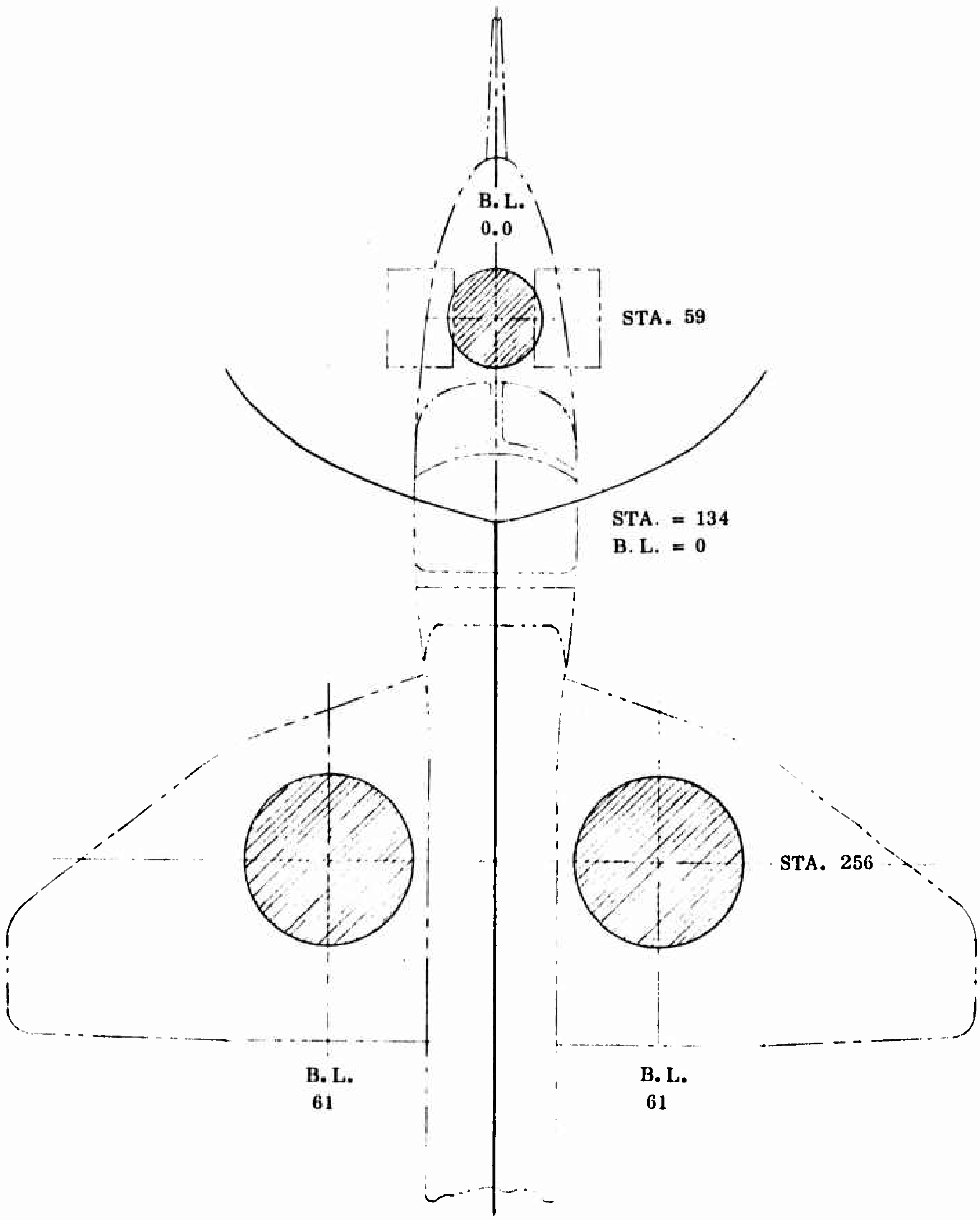


Figure 5. 10 Estimated XV-5A Interaction Zones – Aircraft Controls at Full Up Collective and Full Pitch Up Positions

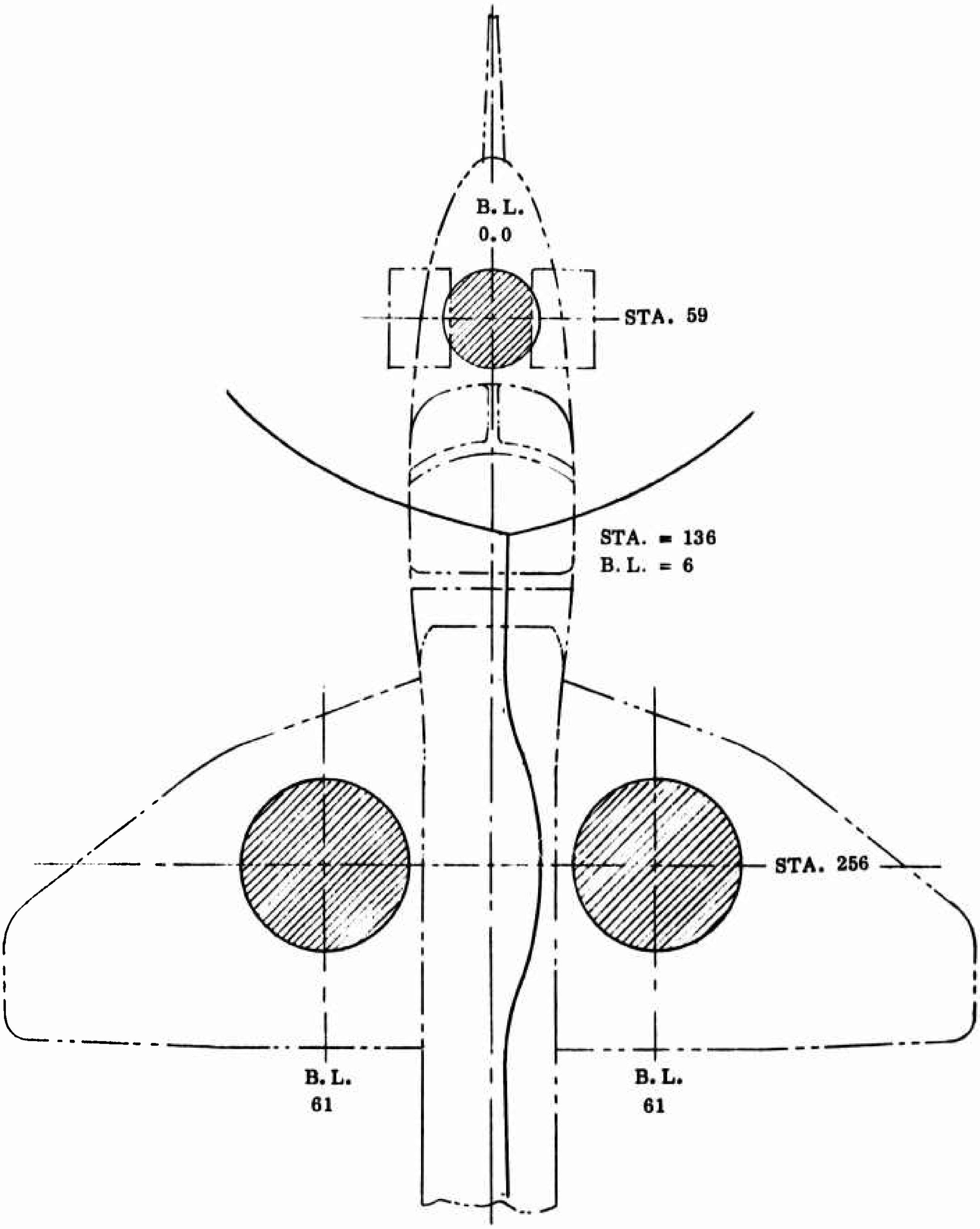


Figure 5. 11 Estimated XV-5A Interaction Zones - Aircraft Controls at Neutral Collective, ± 5% Differential Stagger, and Full Pitch Up Positions

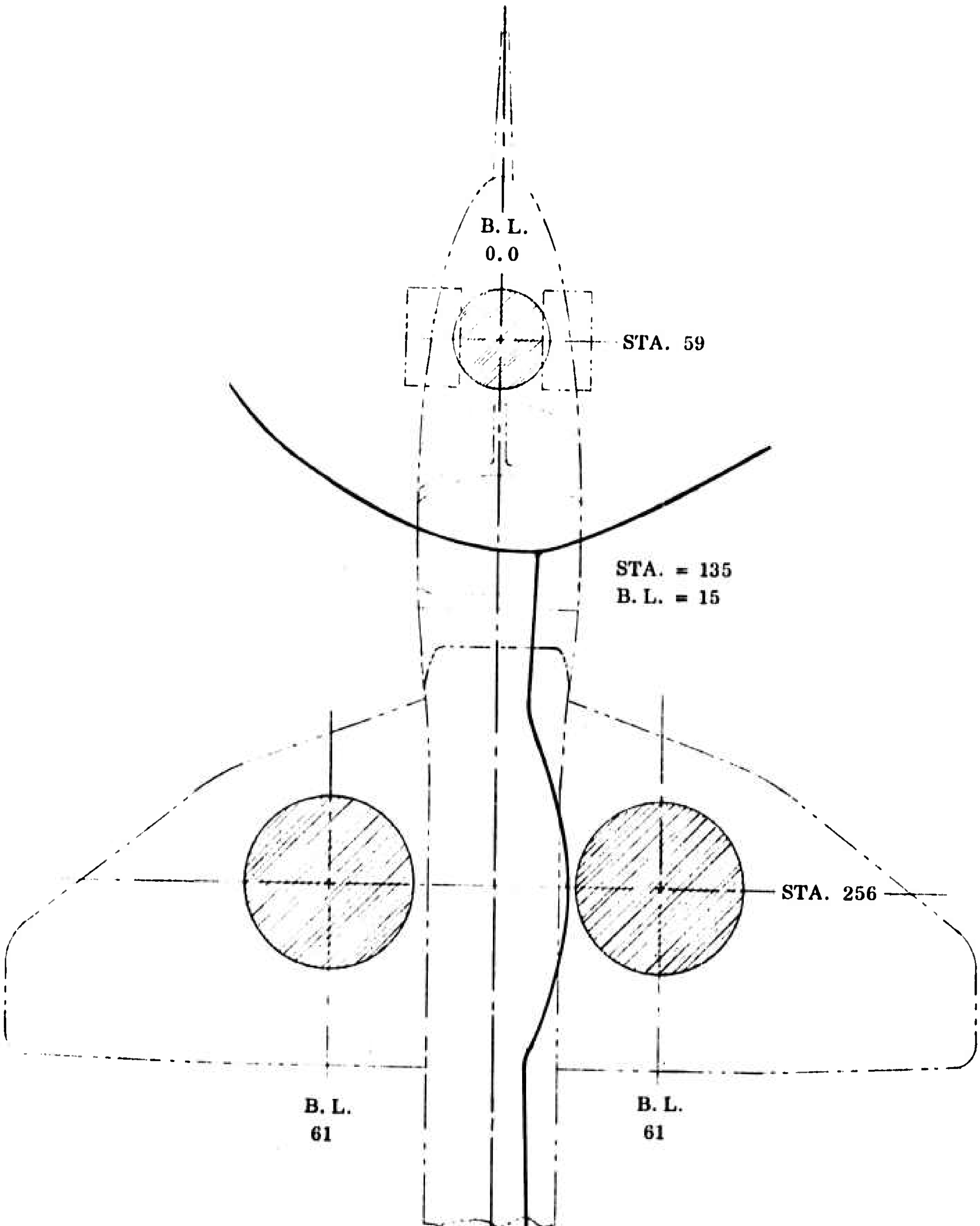


Figure 5. 12 Estimated XV-5A Interaction Zones - Aircraft Controls at Neutral Collective, $\pm$ 12.5% Differential Stagger, and Full Pitch Up Positions

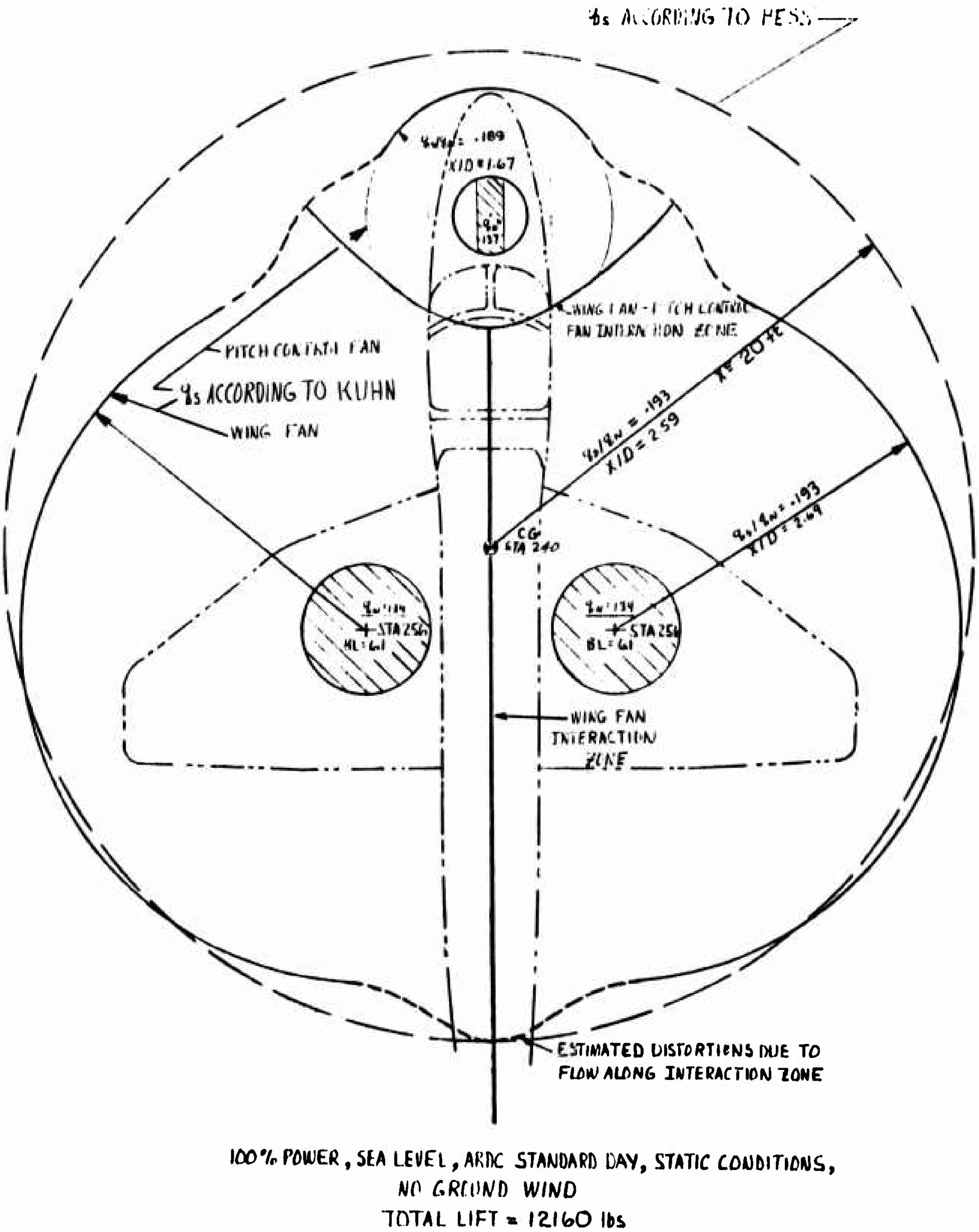


Figure 5.13 Dynamic Pressure Contours, q_s = 26 lb/ft^2 – Aircraft Controls at Neutral Positions

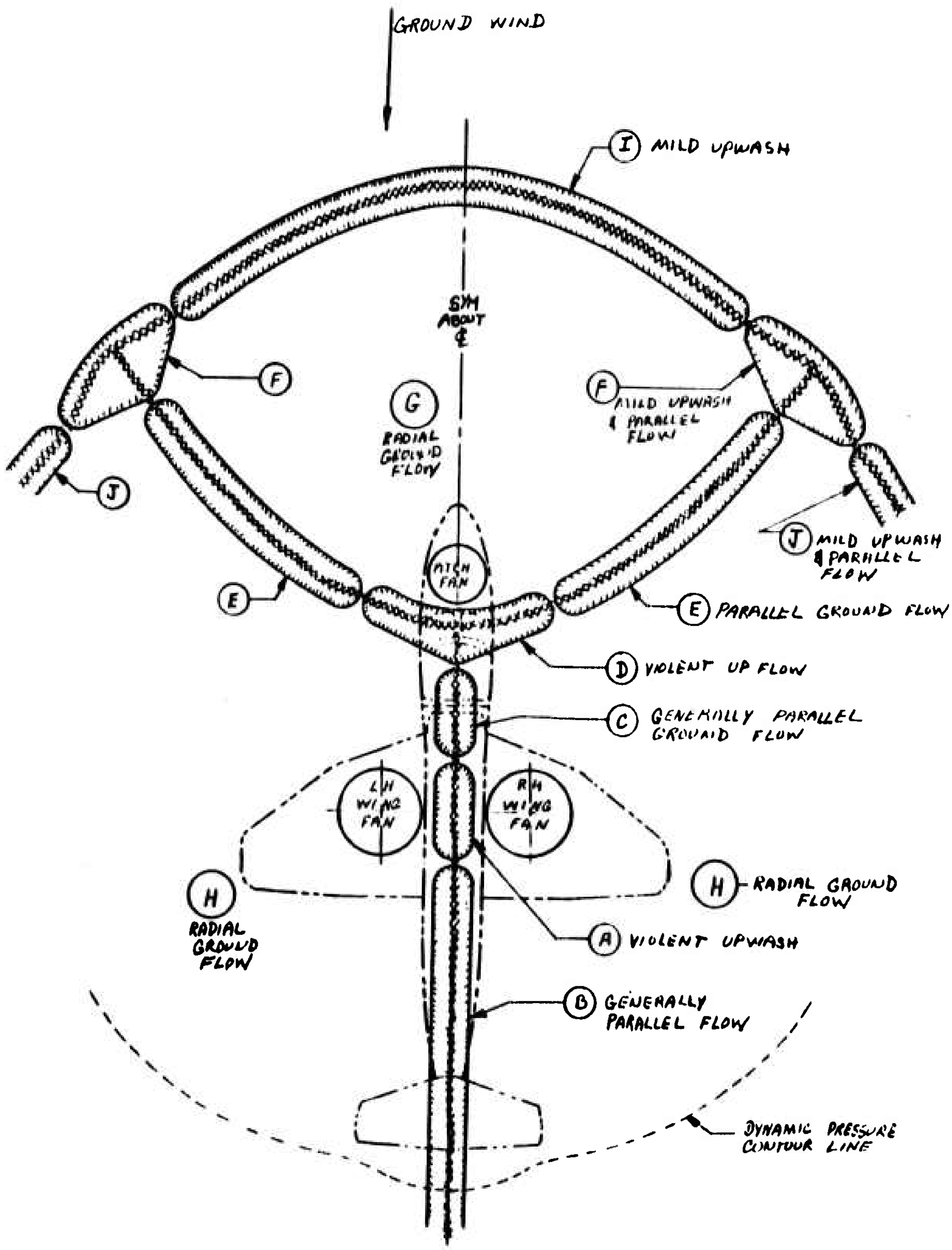


Figure 5. 14 Estimated Classification of Types of Flow Occurring at XV-5A Interaction Zones

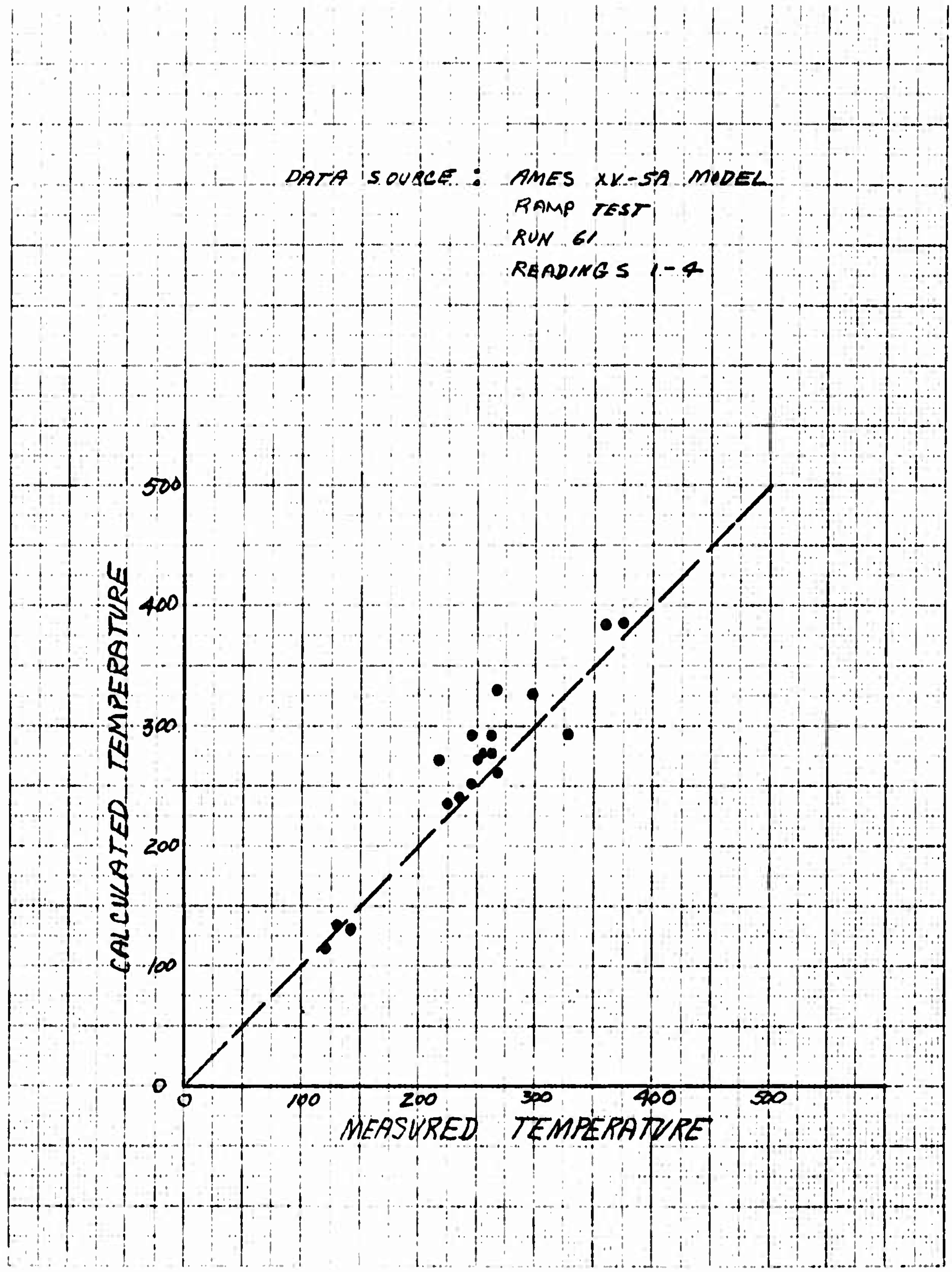


Figure 5.15 Verification of Generalized Temperature Correlation

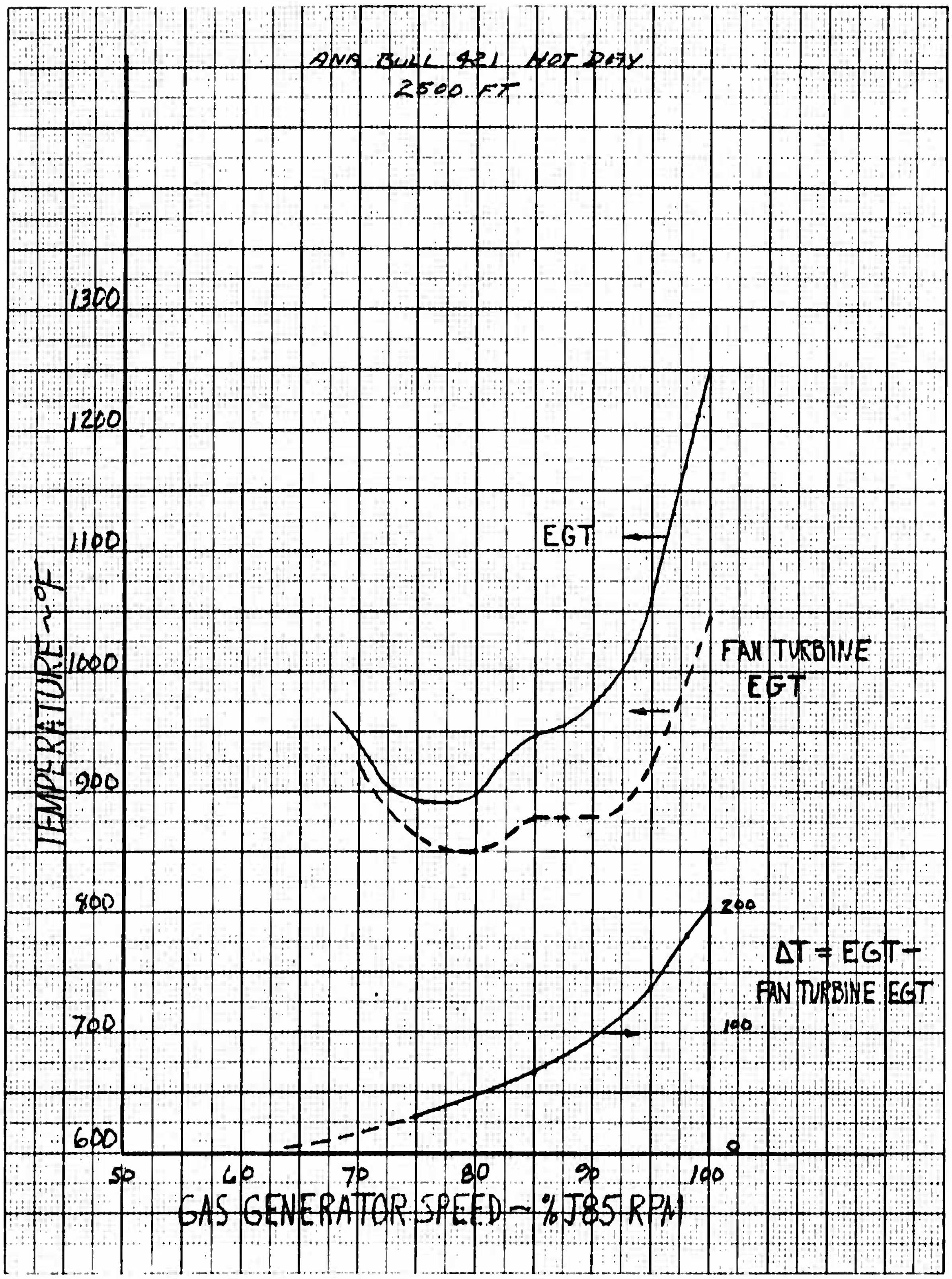


Figure 5.16 Gas Generator and Fan Tip Turbine EGT vs % J85 RPM for XV-5A Aircraft: Hot Day, 2500 Feet

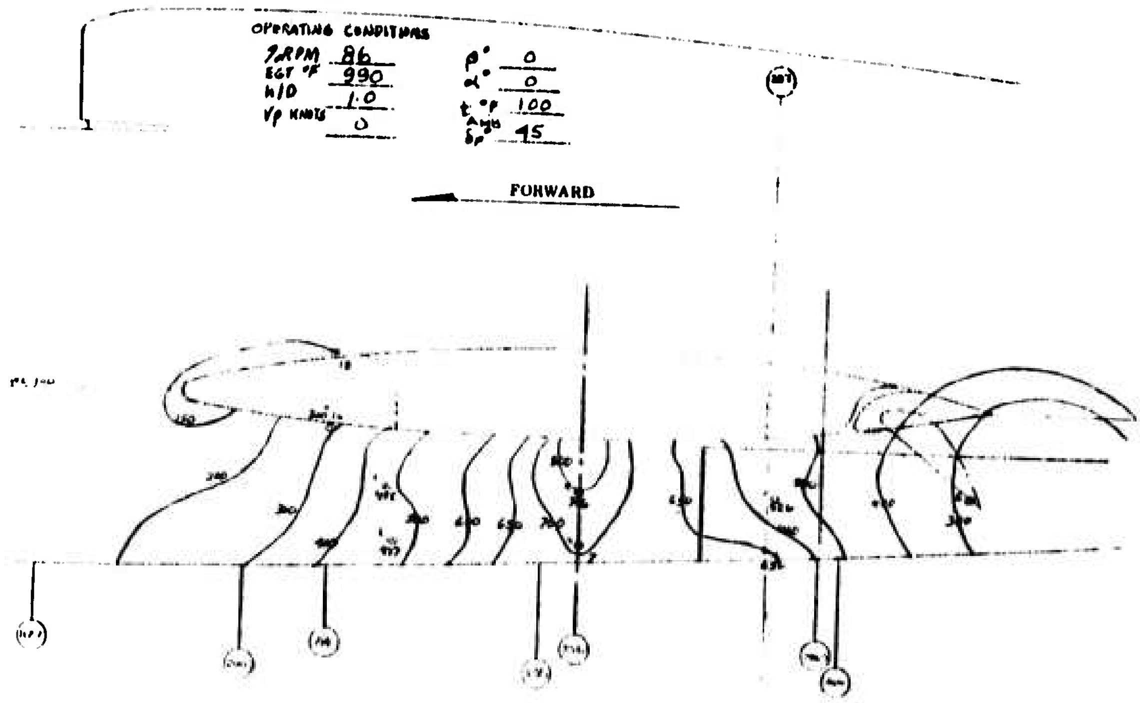


Figure 5. 17 Estimated Mid-Fuselage Gas Isotherms at 86% J85 RPM, $\beta_v = 0°$, and $V_p = 0$ Knots

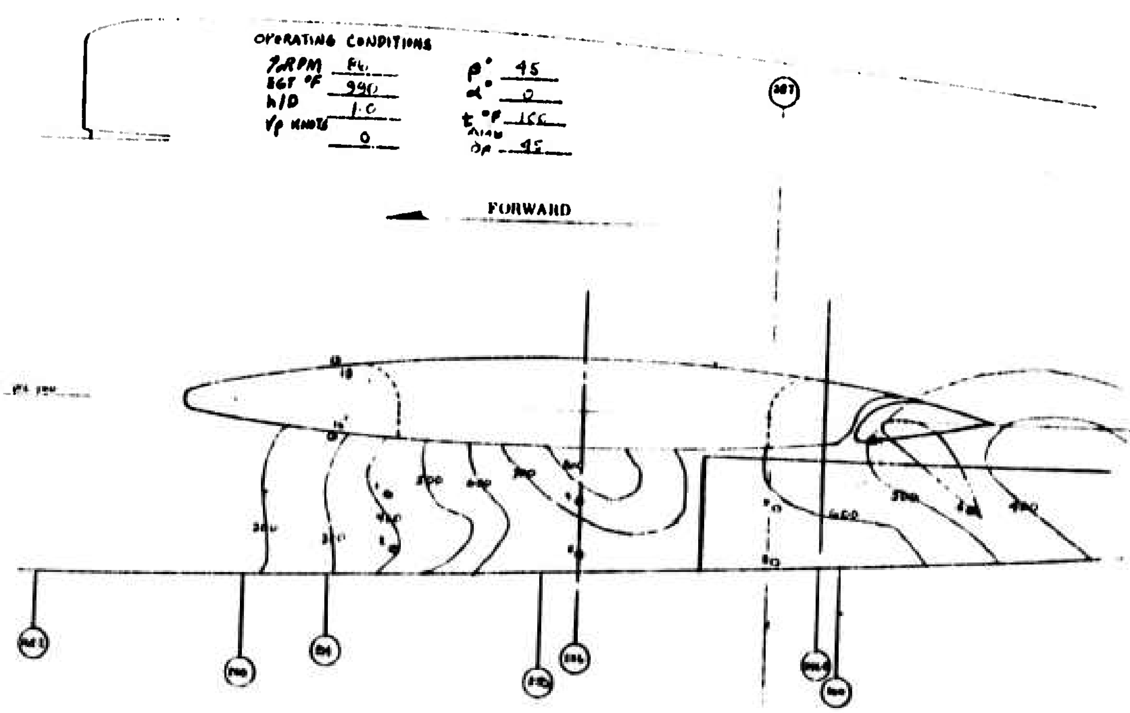


Figure 5. 18 Estimated Mid-Fuselage Gas Isotherms at 86% J85 RPM, $\beta_v = 45°$, and $V_p = 0$ Knots

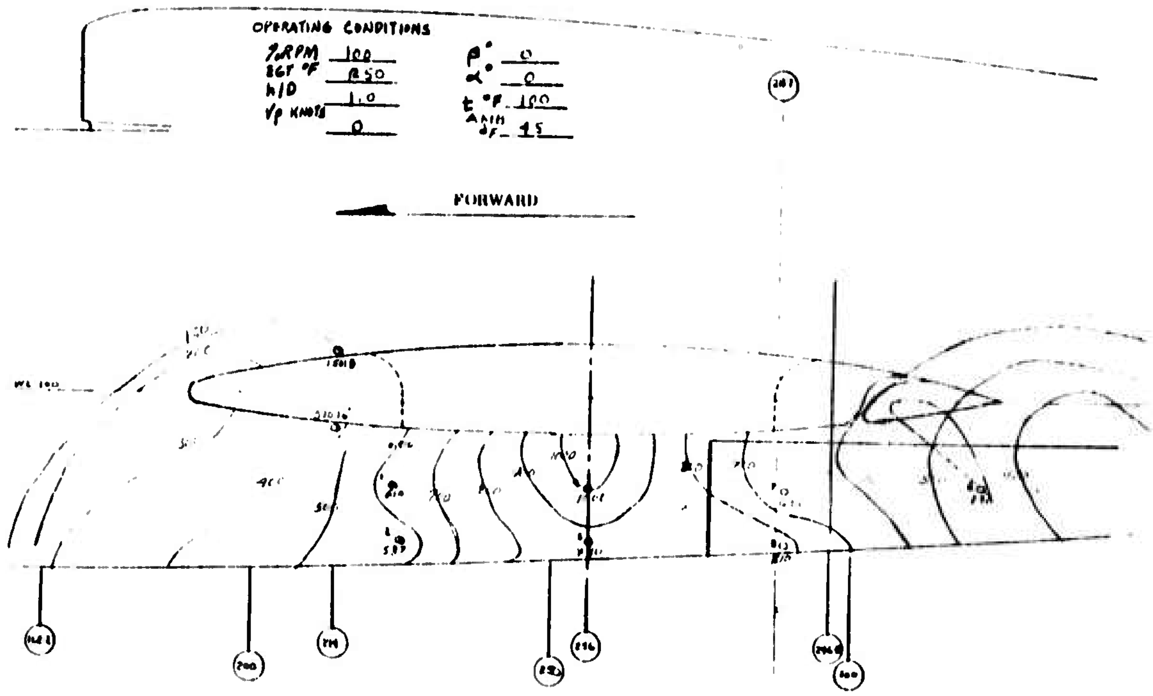


Figure 5.19 Estimated Mid-Fuselage Gas Isotherms at 100% J85 RPM, $\beta_v = 0°$, and $V_p = 0$ Knots

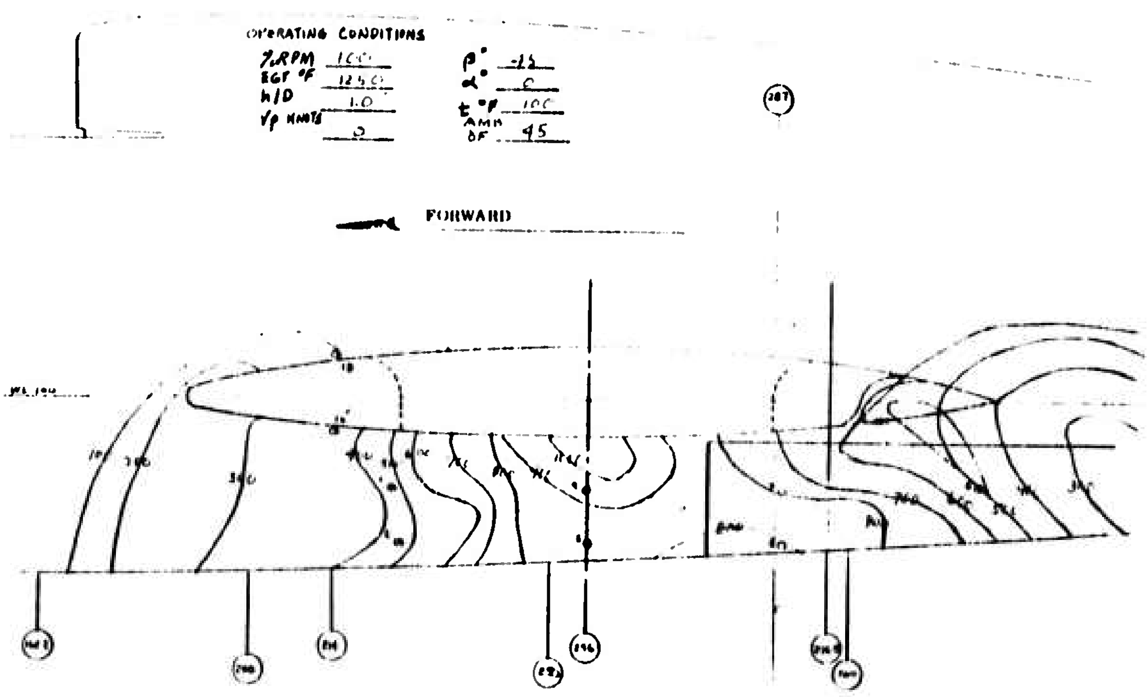


Figure 5.20 Estimated Mid-Fuselage Gas Isotherms at 100% J85 RPM, $\beta_v = 45°$, and $V_p = 0$ Knots

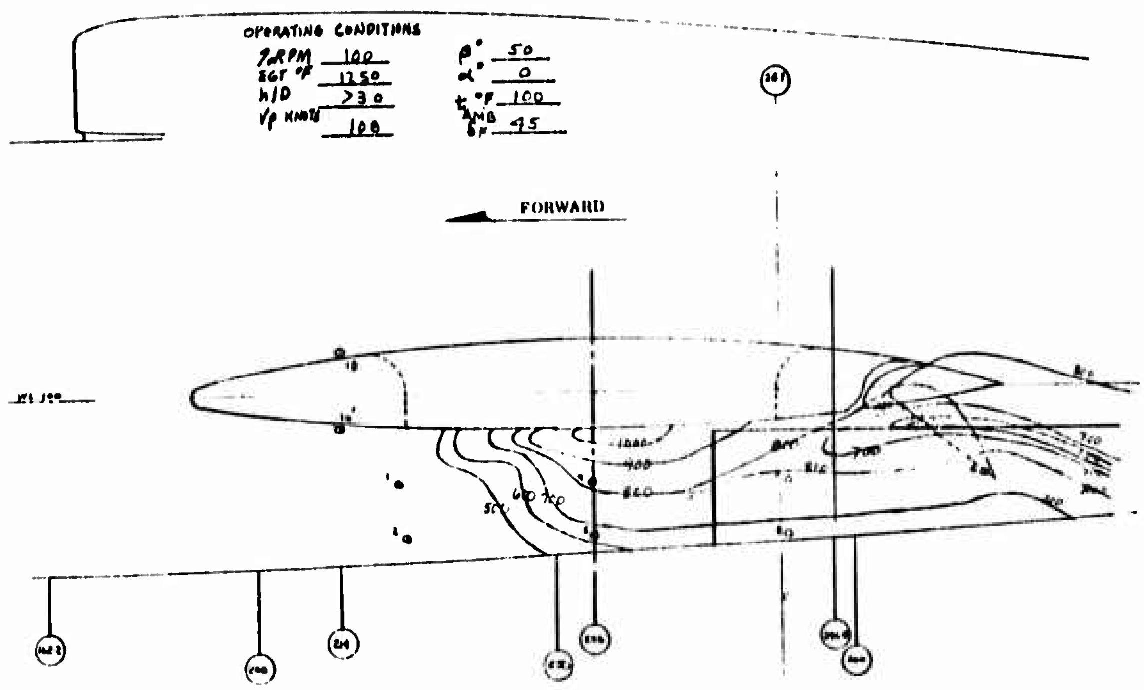


Figure 5.21 Estimated Mid-Fuselage Gas Isotherms at 100% J85 RPM, $\beta_V = 50°$, and V_p = 108 Knots

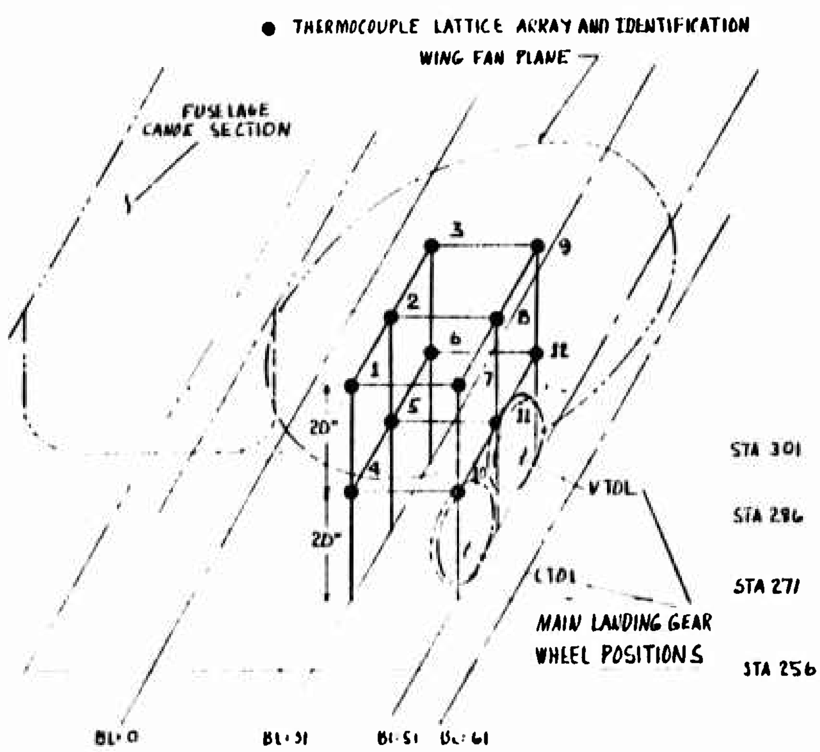


Figure 5.22 Main Landing Gear Thermocouple Lattice Array

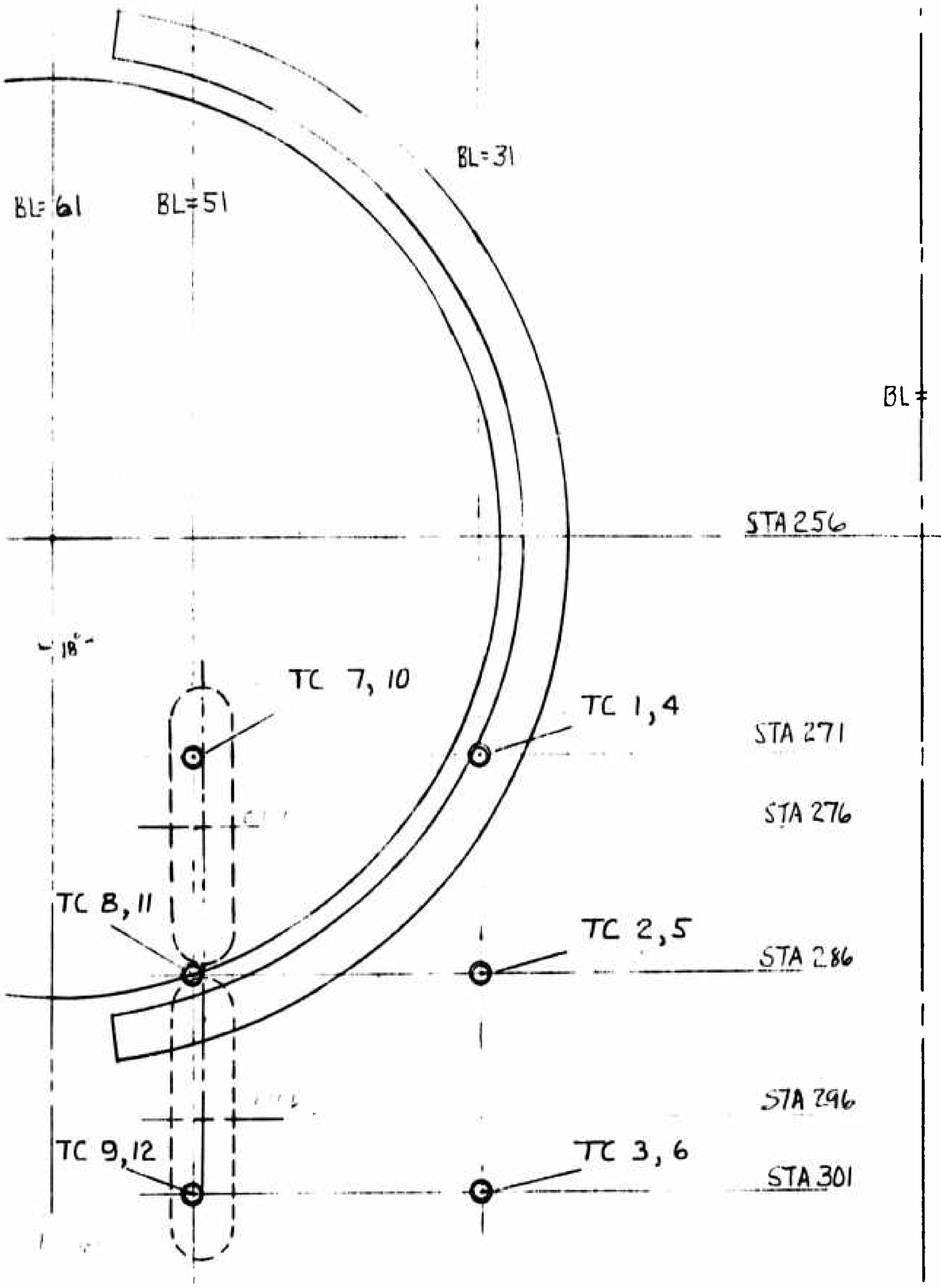


Figure 5.23 Top View-Main Landing Gear Instrumentation

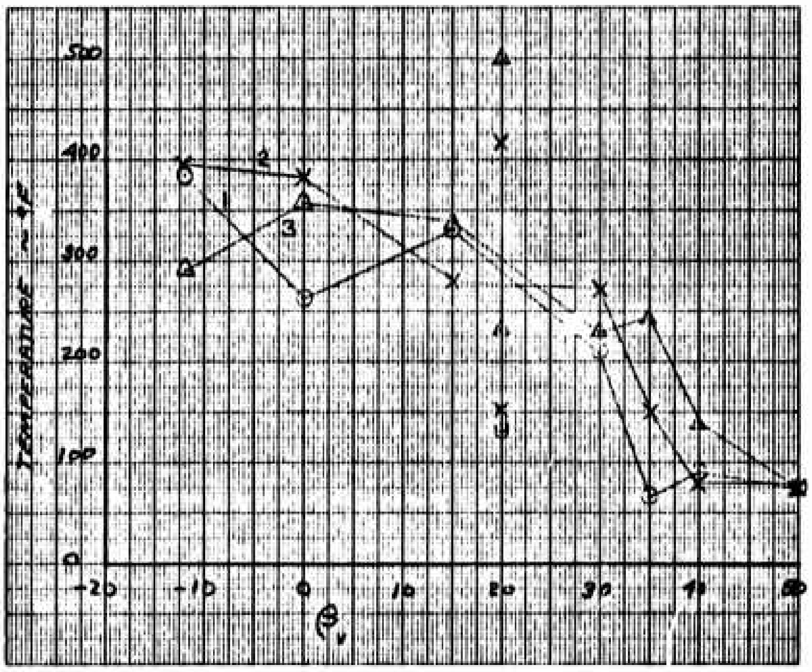


Figure 5. 24(a) Effect of Fan Stream Vector on Landing Gear Environmental Temperature - TC's 1, 2, and 3

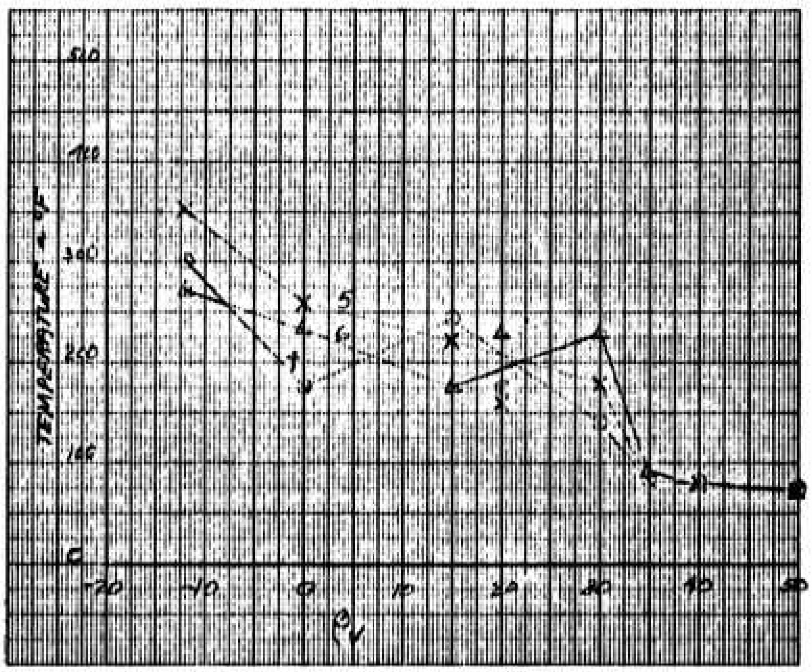


Figure 5. 24(b) Effect of Fan Stream Vector on Landing Gear Environmental Temperature - TC's 4, 5, and 6

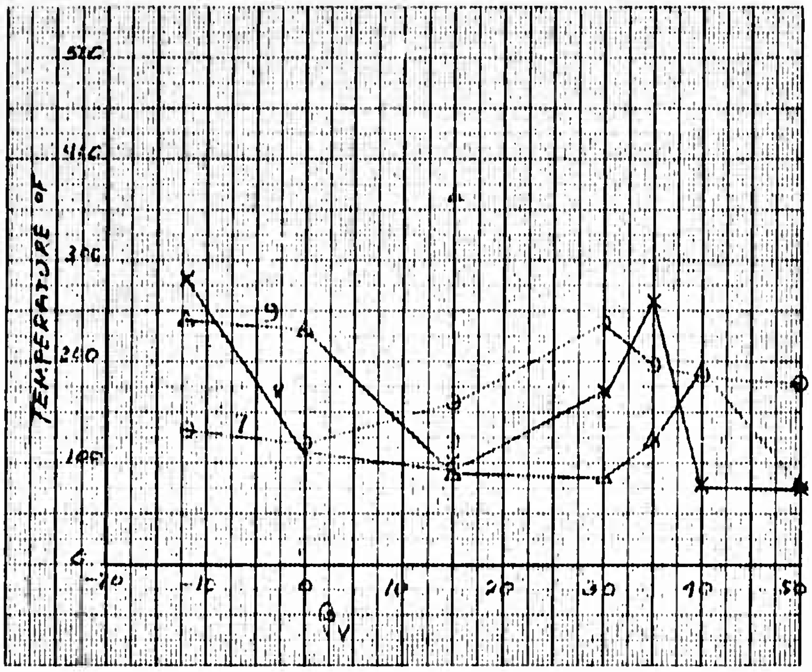


Figure 5. 24(c) Effect of Fan Stream Vector on Landing Gear Environmental Temperature - TC's 7, 8, and 9

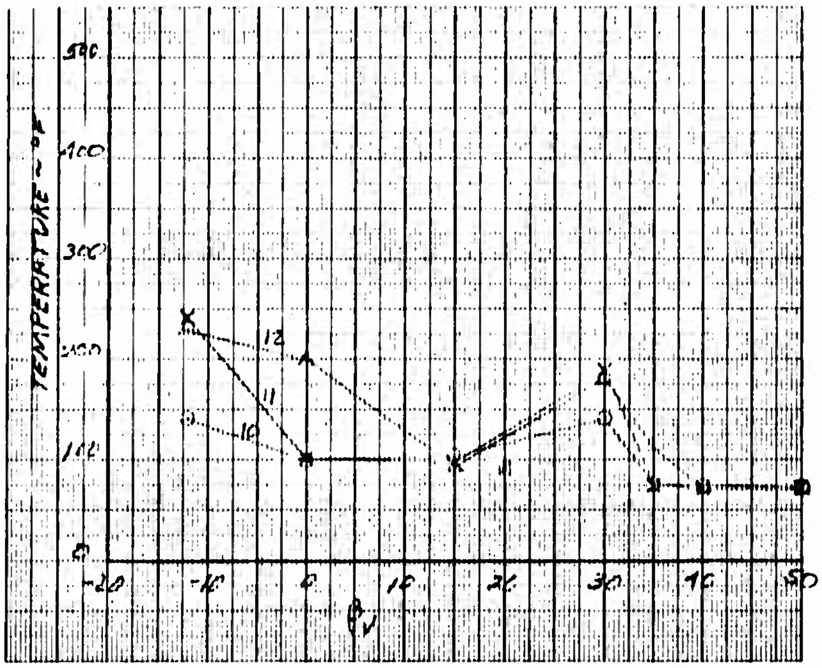


Figure 5. 24(d) Effect of Fan Stream Vector on Landing Gear Environmental Temperature - TC's 10, 11, and 12

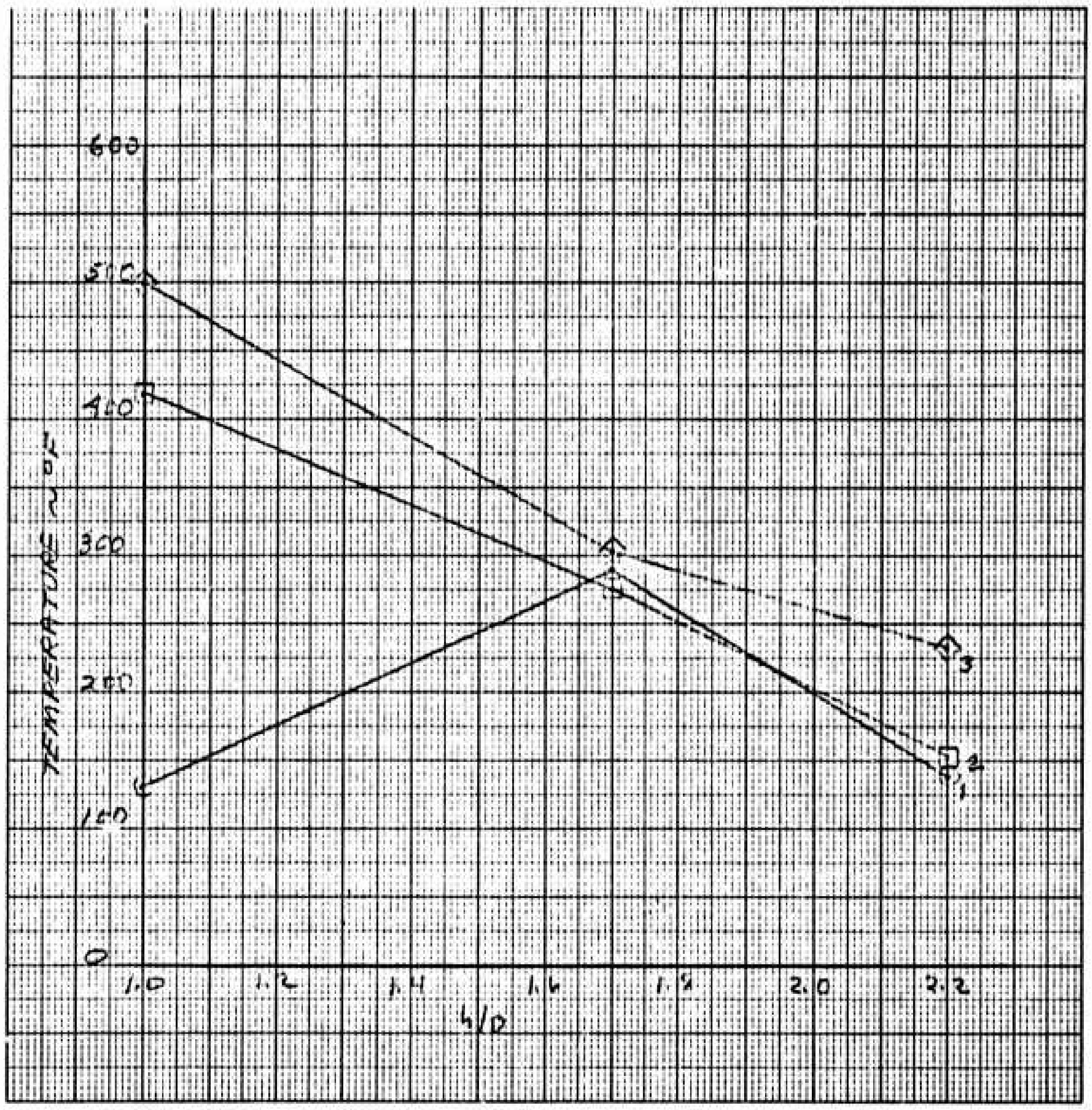


Figure 5.25 Effect of Aircraft Height on Landing Gear Environmental Temperatures - TC's 1, 2, and 3 .

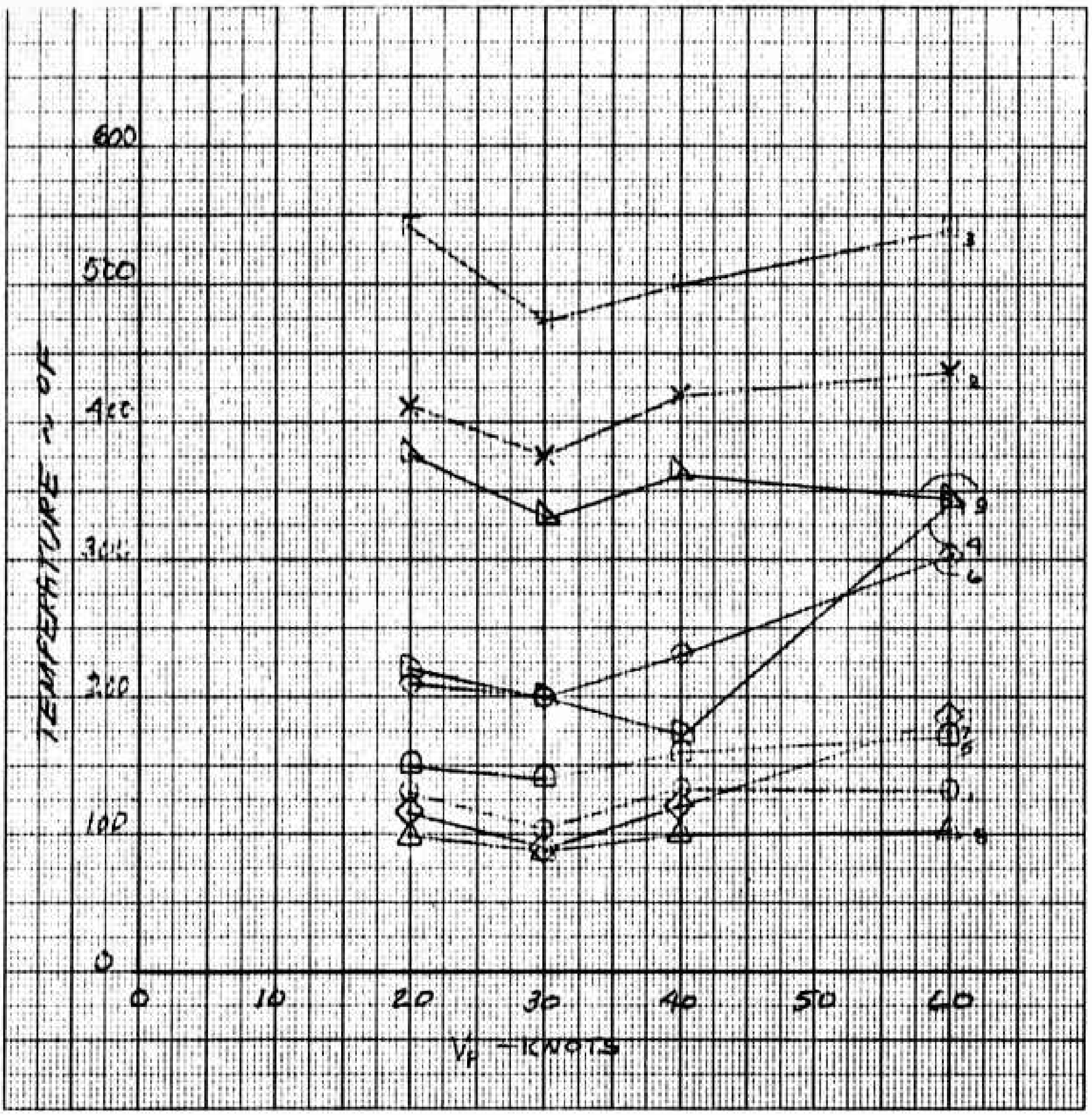


Figure 5. 26 Effect of Aircraft Velocity on Landing Gear Environmental Temperatures

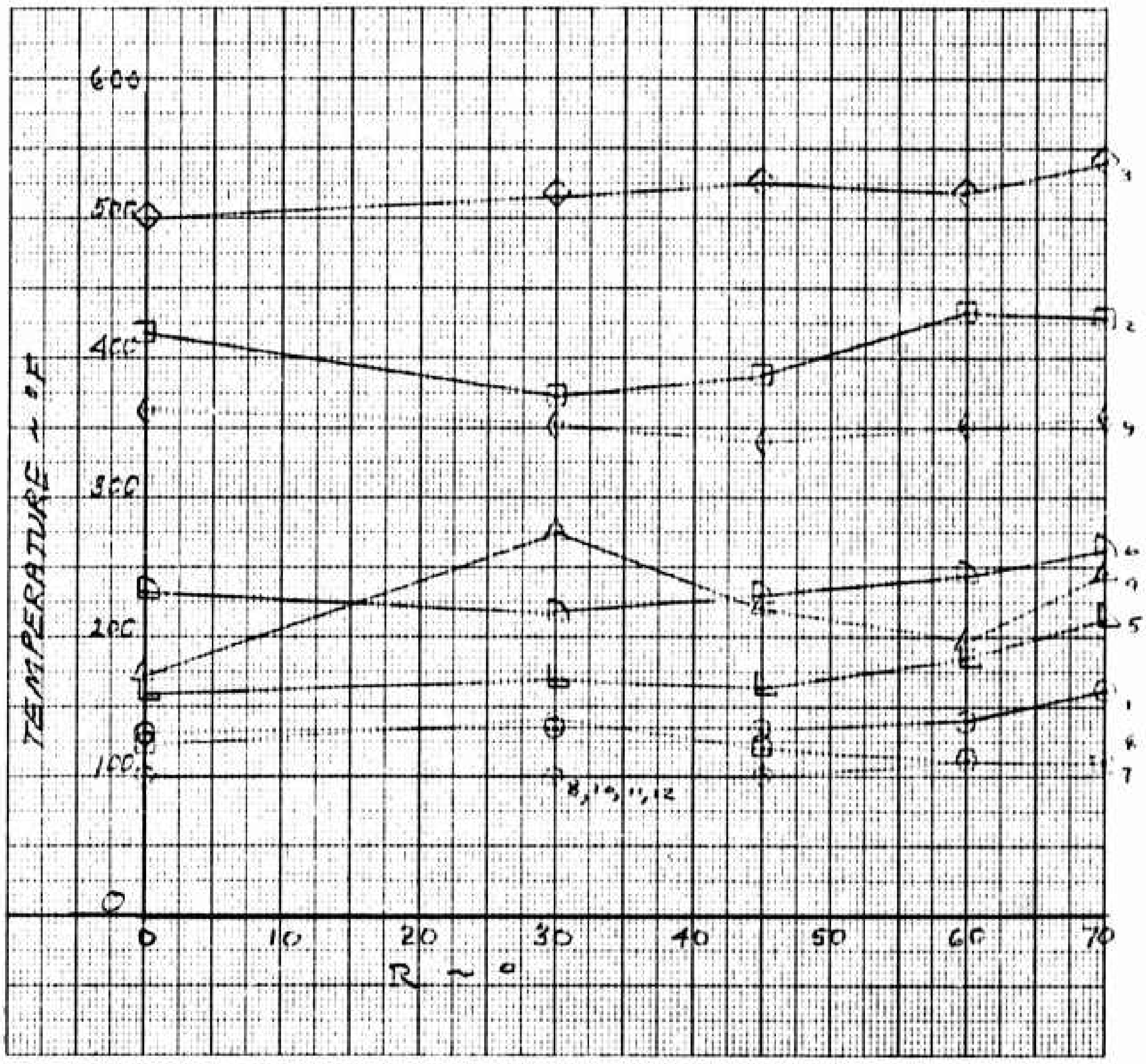


Figure 5. 27 Effect of Pitch Control Thrust Reverser Door Position on Landing Gear Environmental Temperatures

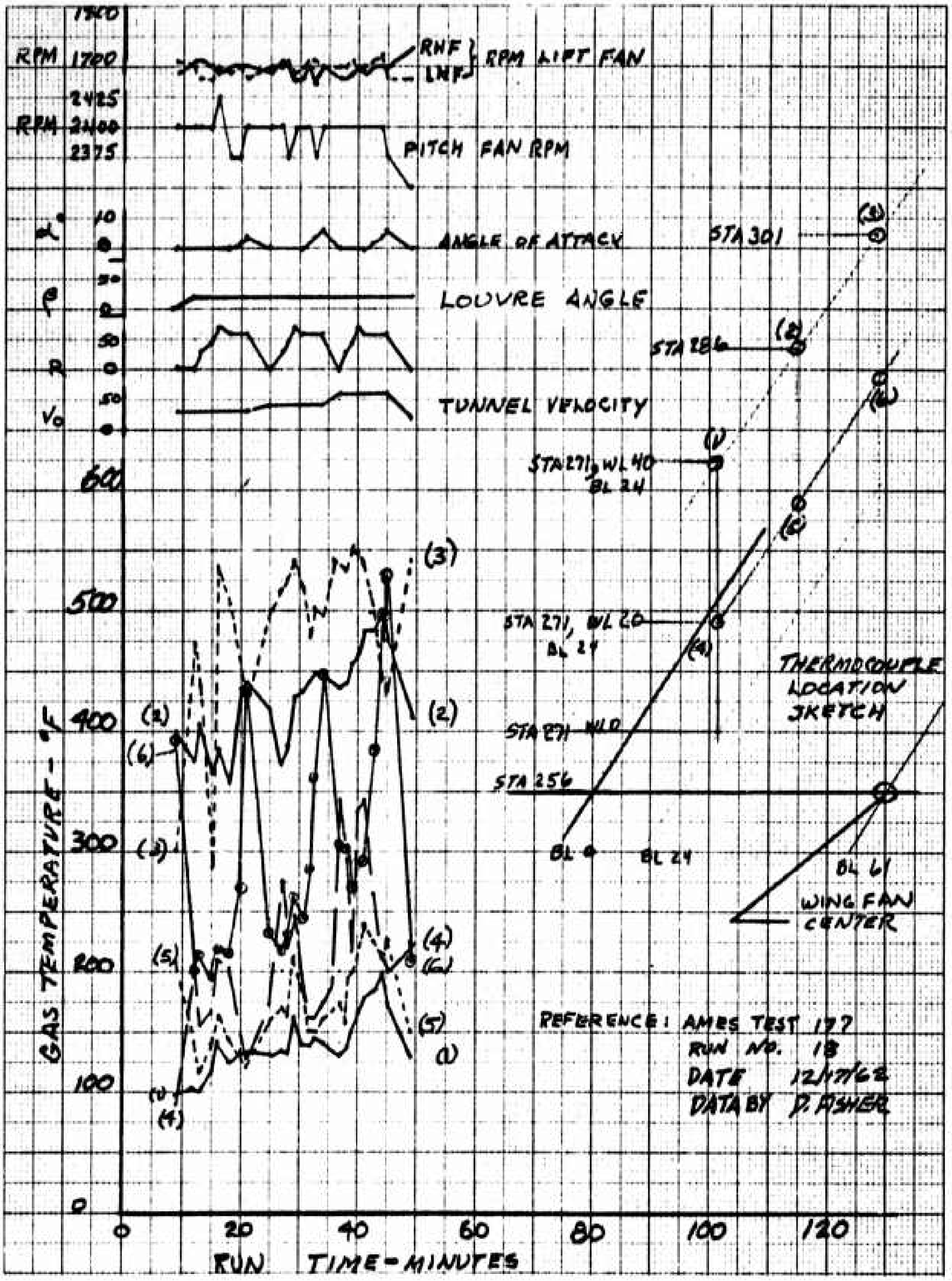


Figure 5. 28 Gas Temperatures in Vicinity of Landing Gear vs Time and Aircraft Control Inputs

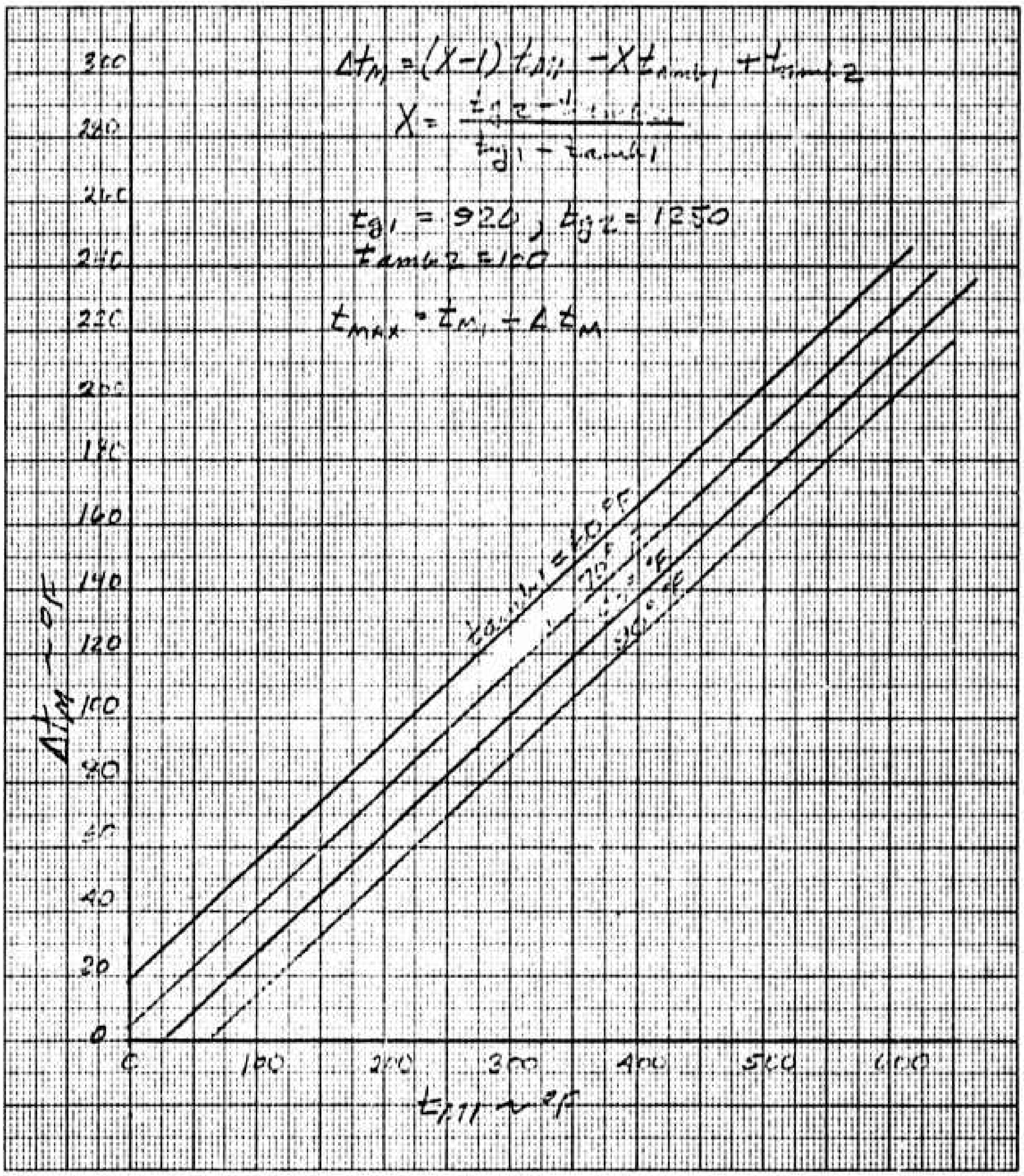


Figure 5.29 Correction Factor to Obtain Estimated Maximum Landing Gear Environmental Temperatures

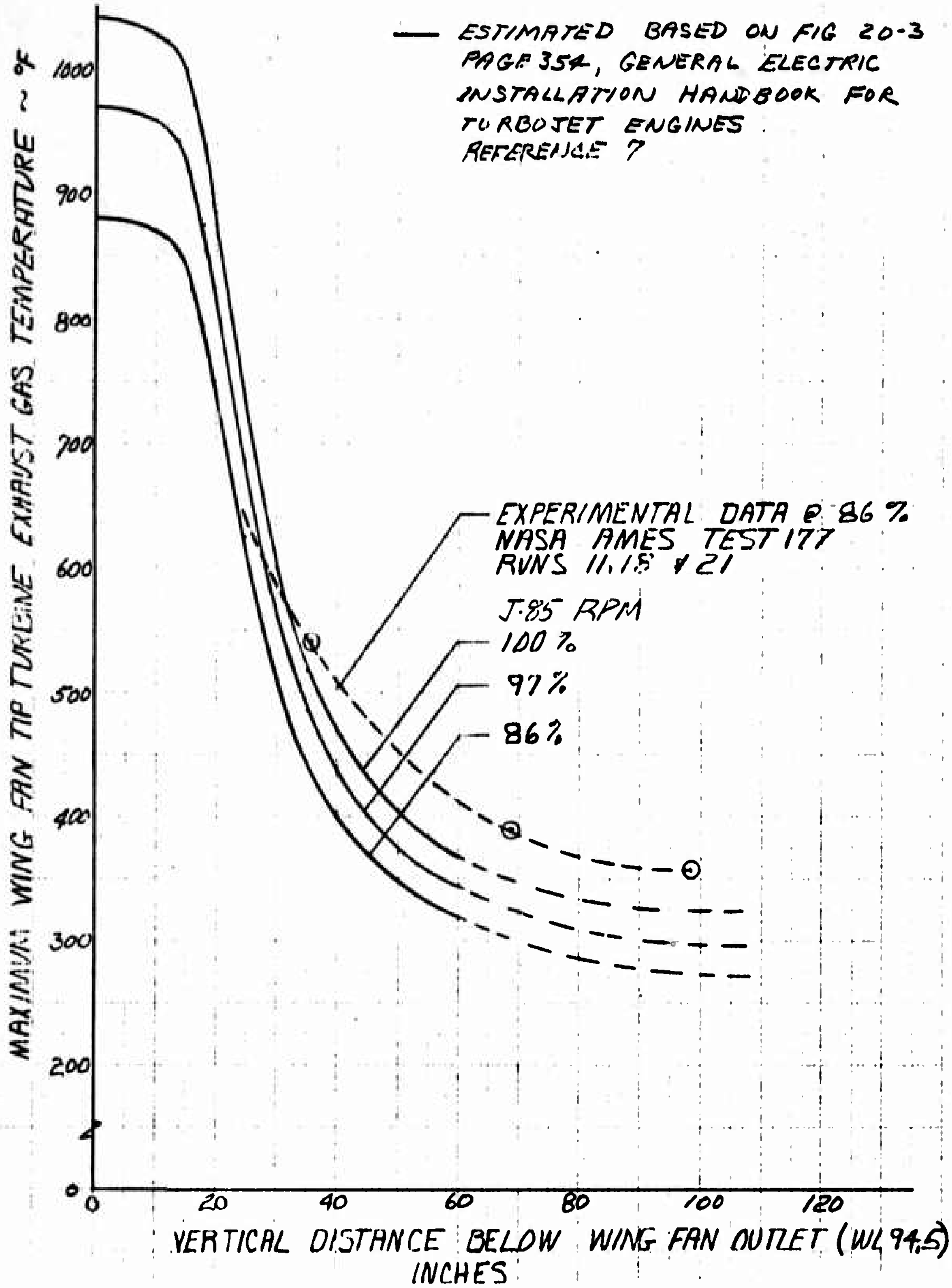


Figure 5.30 Comparison of Estimated and Experimental Tip-Turbine Exhaust Temperature Decay vs Distance

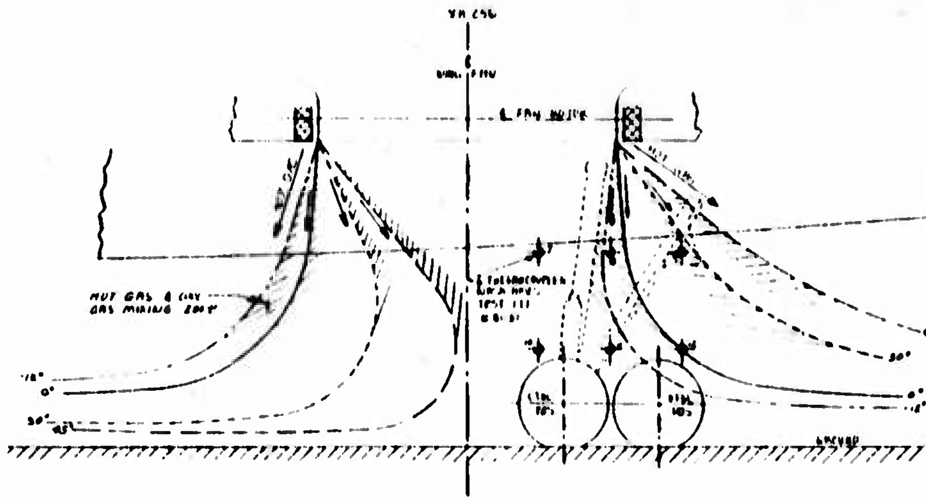


Figure 5.31 Estimated Effect of Vectoring on XV-5A Downwash at h/D = 1.0, V_p = 0 Knots

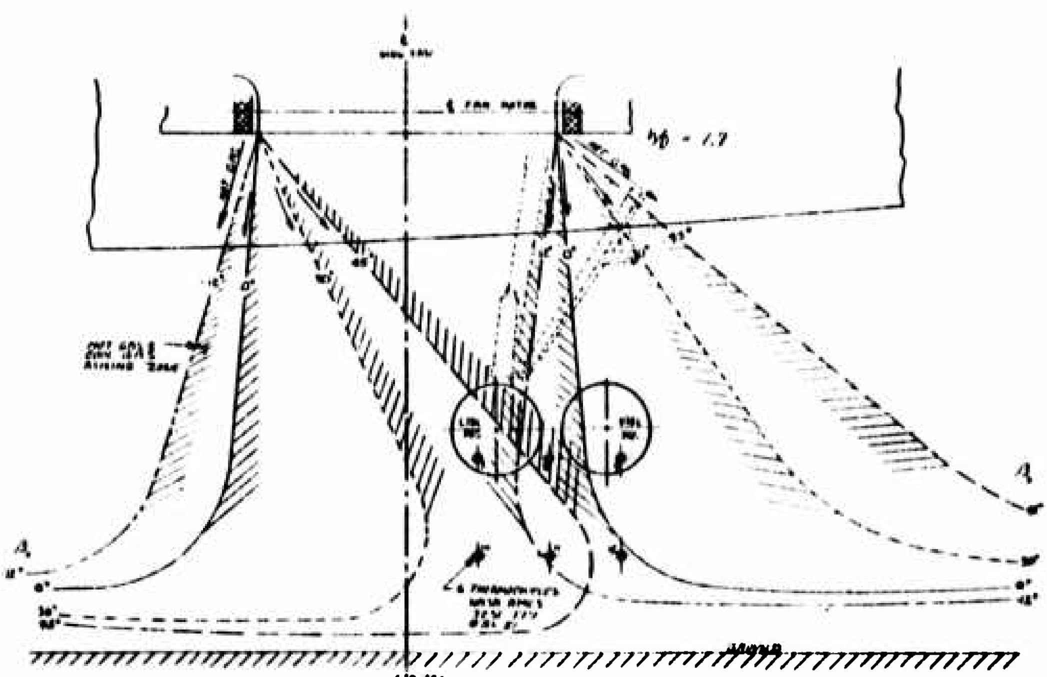


Figure 5.32 Estimated Effect of Vectoring on XV-5A Downwash at h/D = 1.7, V_p = 0 Knots

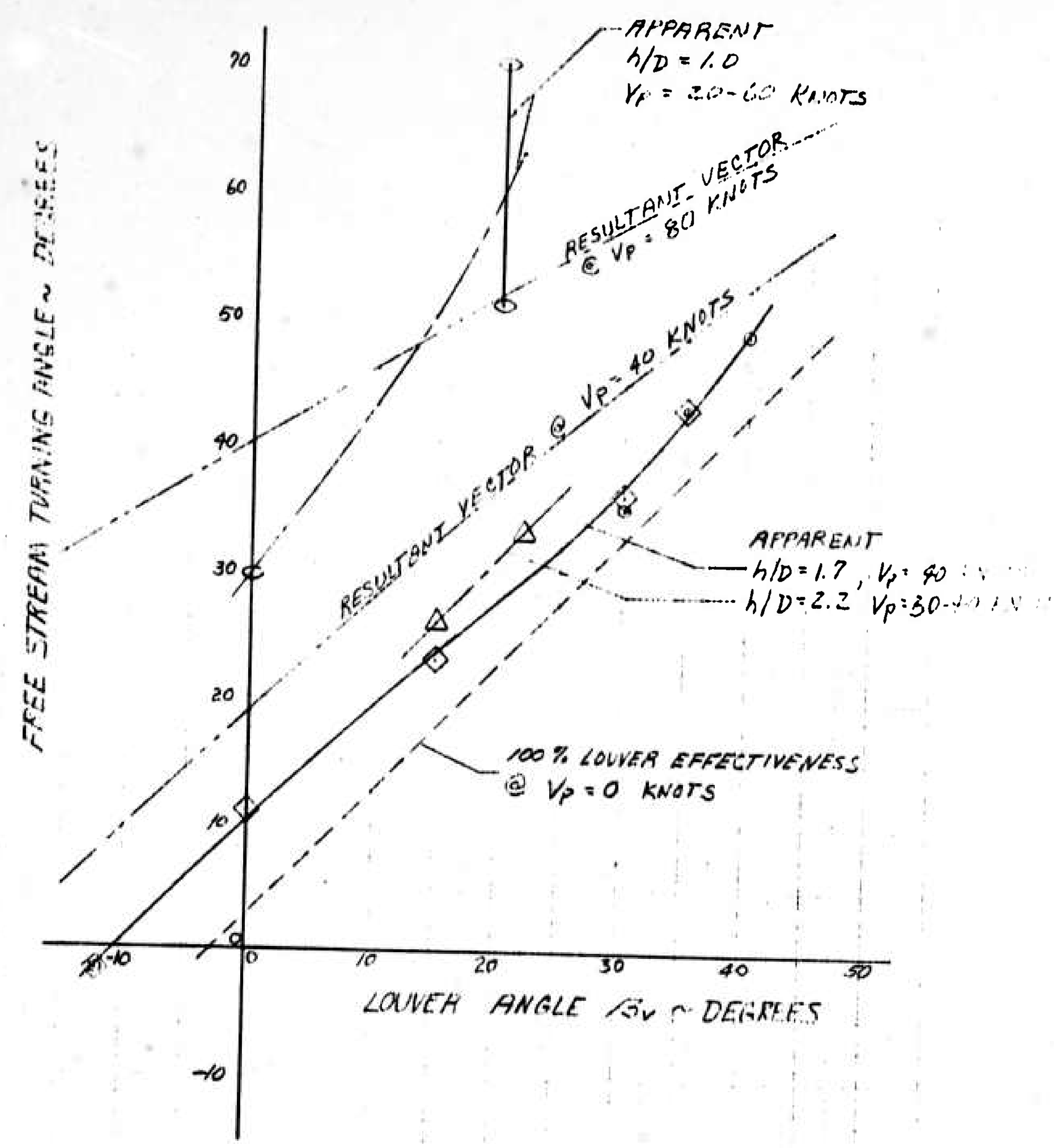


Figure 5.33 **Apparent Resultant Downwash Vector vs Louver Angle**

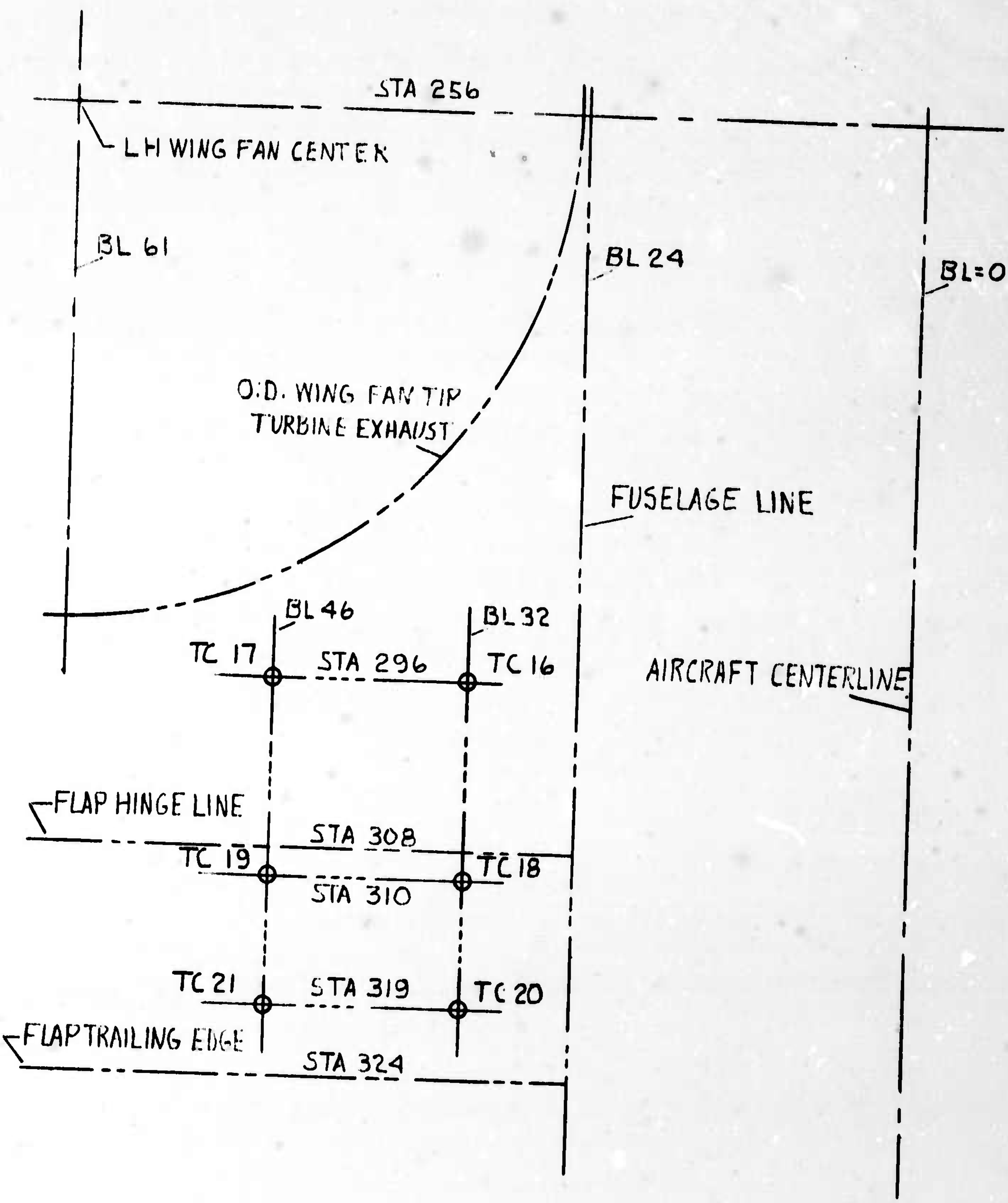


Figure 5.34 Lower Wing and Flap Surface Environment Instrumentation

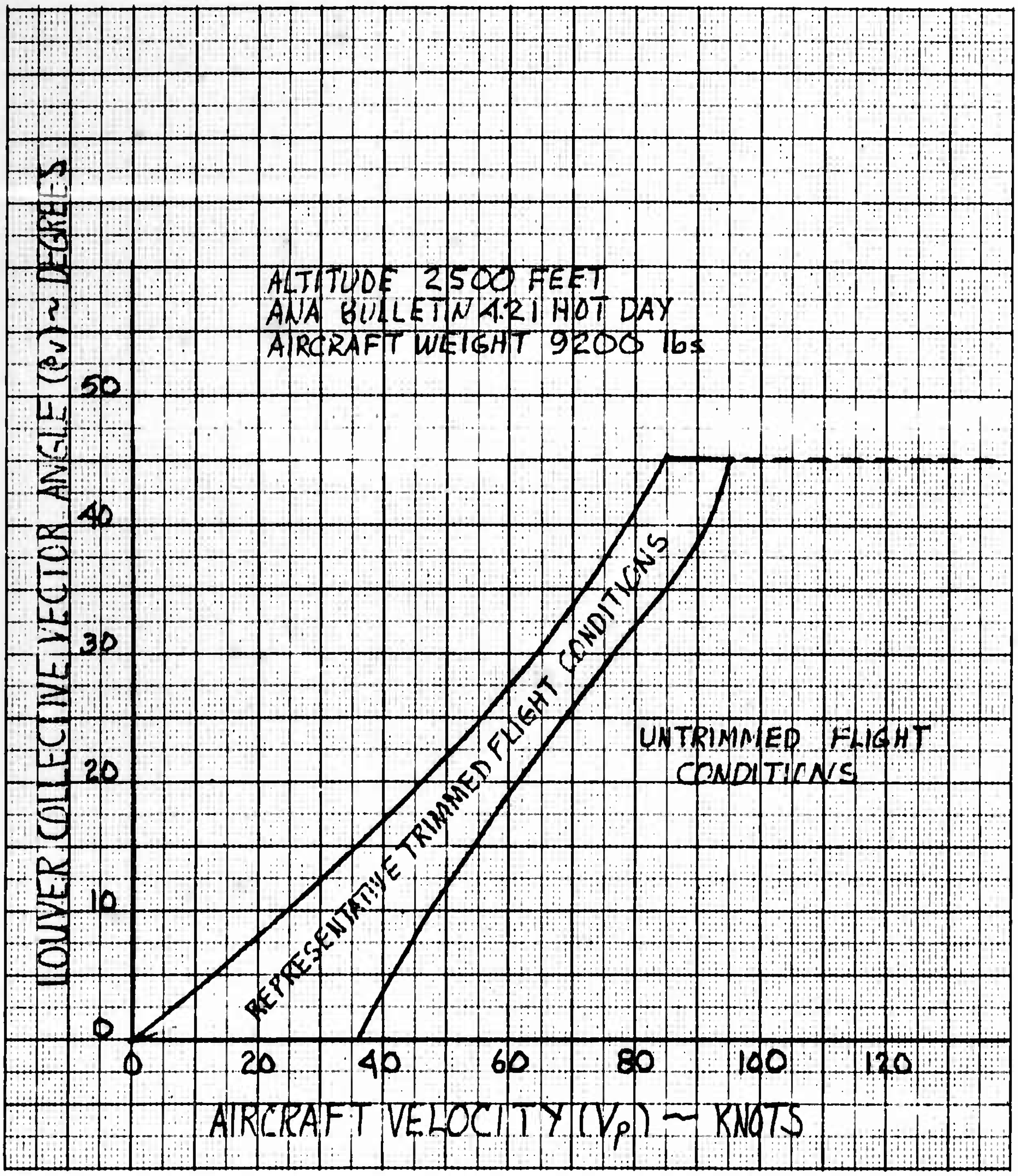


Figure 5.35 Trimmed Flight Corridor of Louver Angle vs Aircraft Velocity

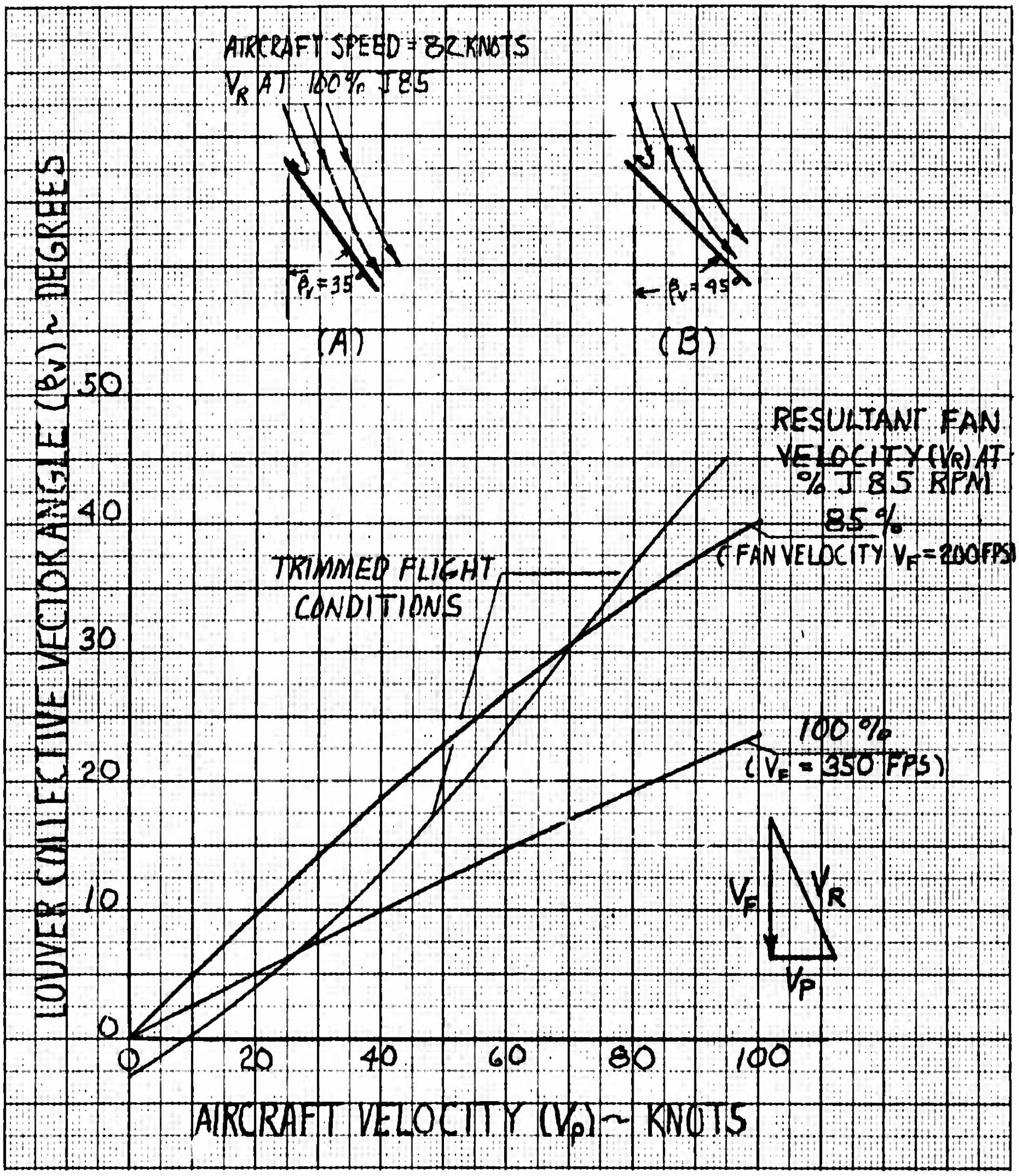


Figure 5.36 Comparison of Estimated Resultant Fan Stream Velocity Vector and Trimmed Louver Angle Setting vs Aircraft Velocity

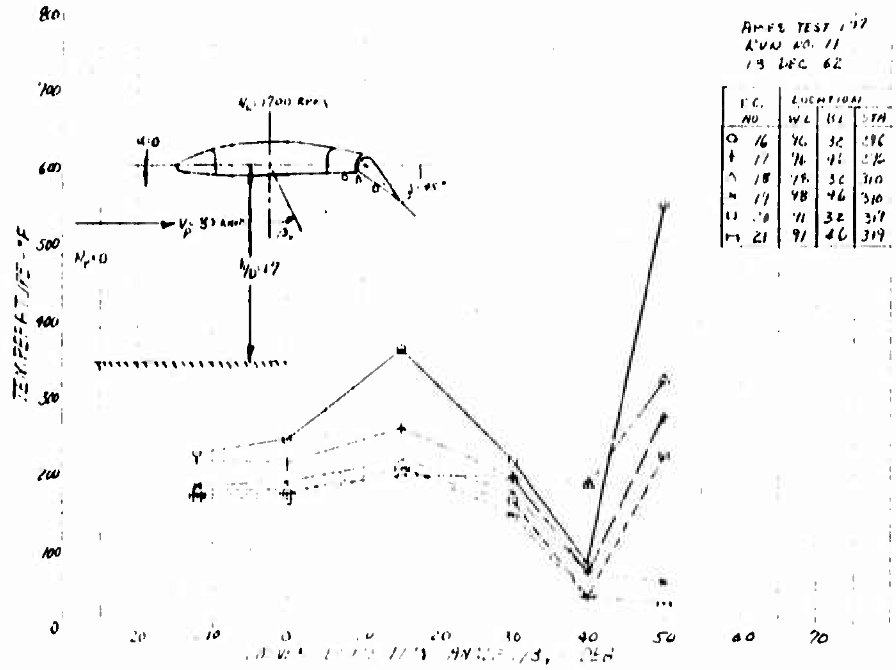


Figure 5.37 Lower Wing and Flap Environment vs Louver Angle: V_p = 30 Knots, $\alpha = 0°$, h/D = 1.7

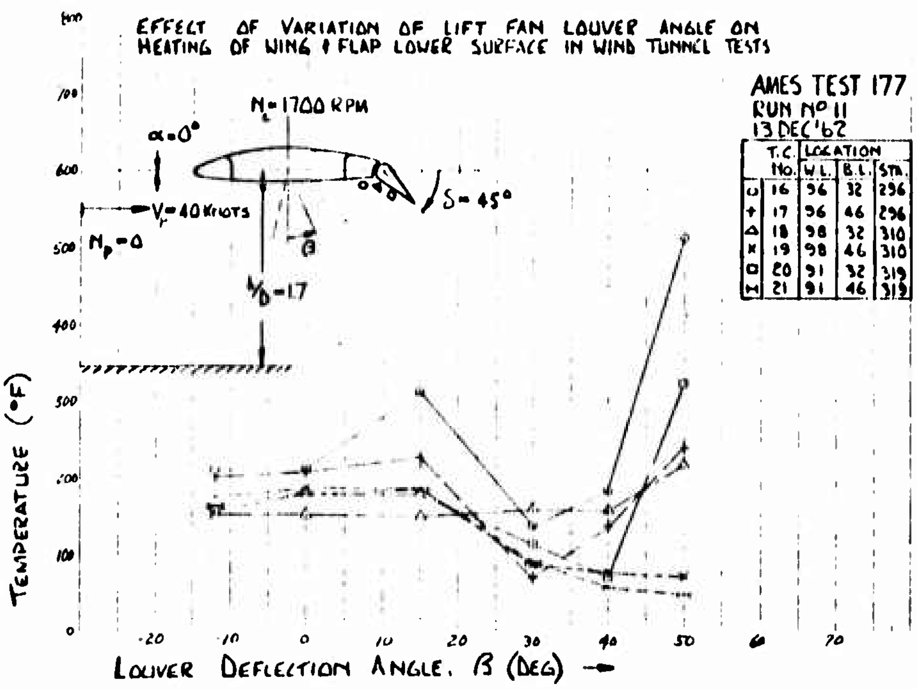


Figure 5.38 Lower Wing and Flap Environment vs Louver Angle: V_p = 40 Knots, $\alpha = 0°$. h/D = 1.7

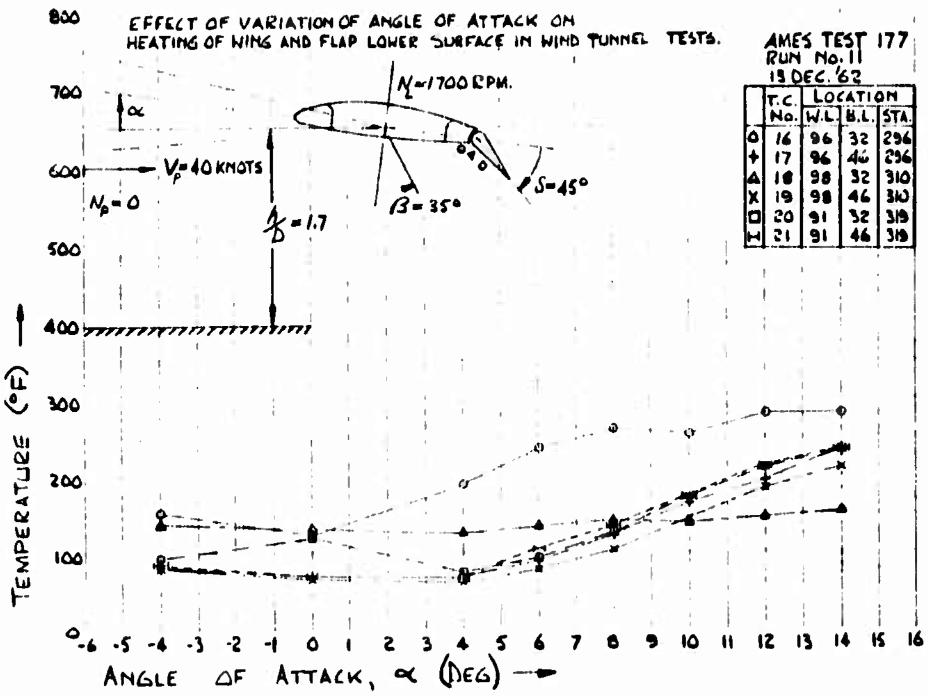


Figure 5.39 Lower Wing and Flap Environment vs Angle of Attack: $V_p = 40$ Knots, $\beta_V = 35°$, $h/D = 1.7$

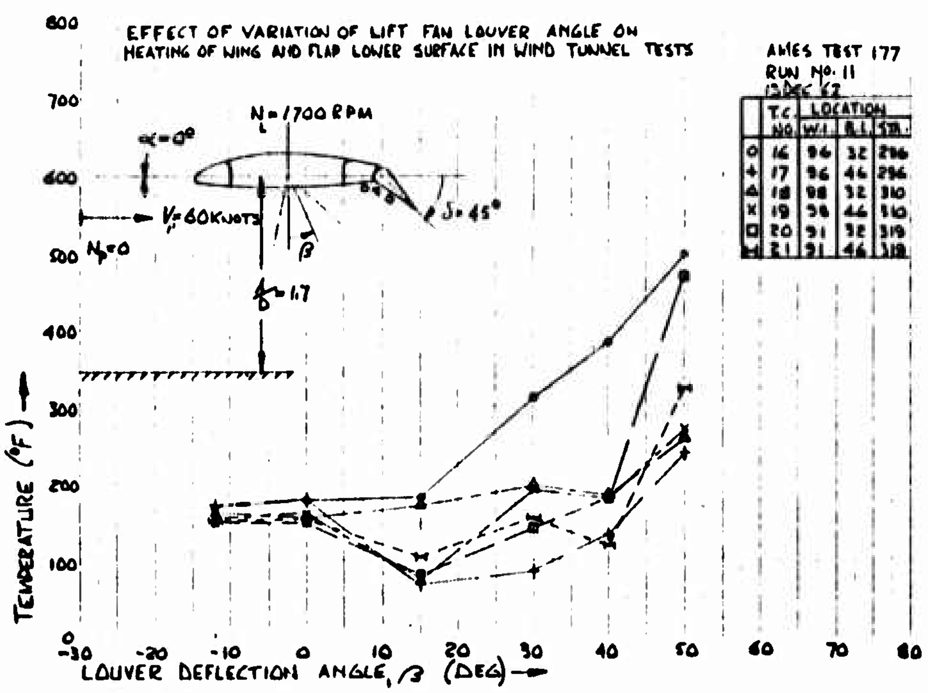
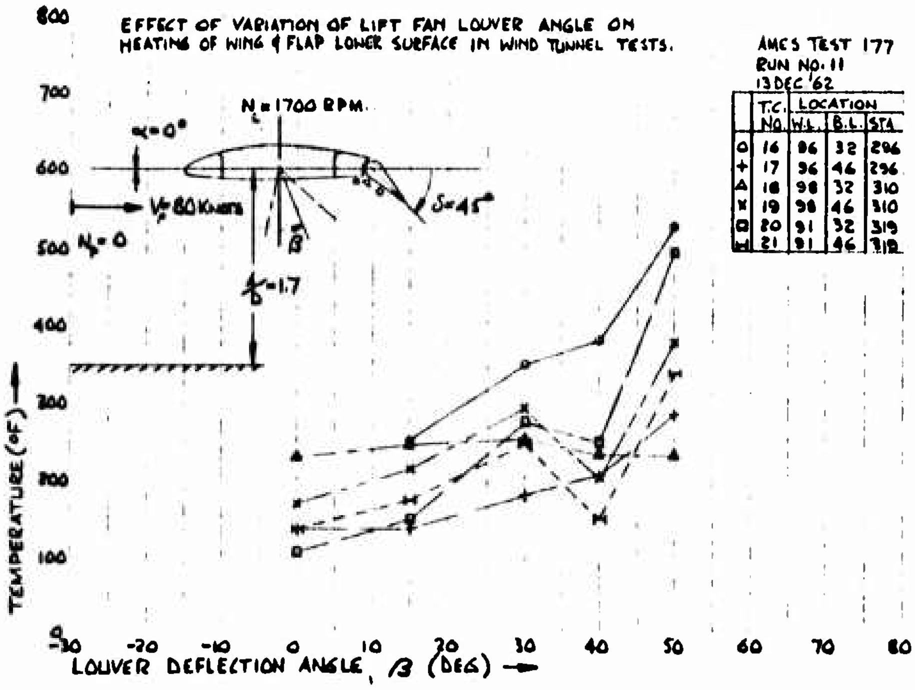
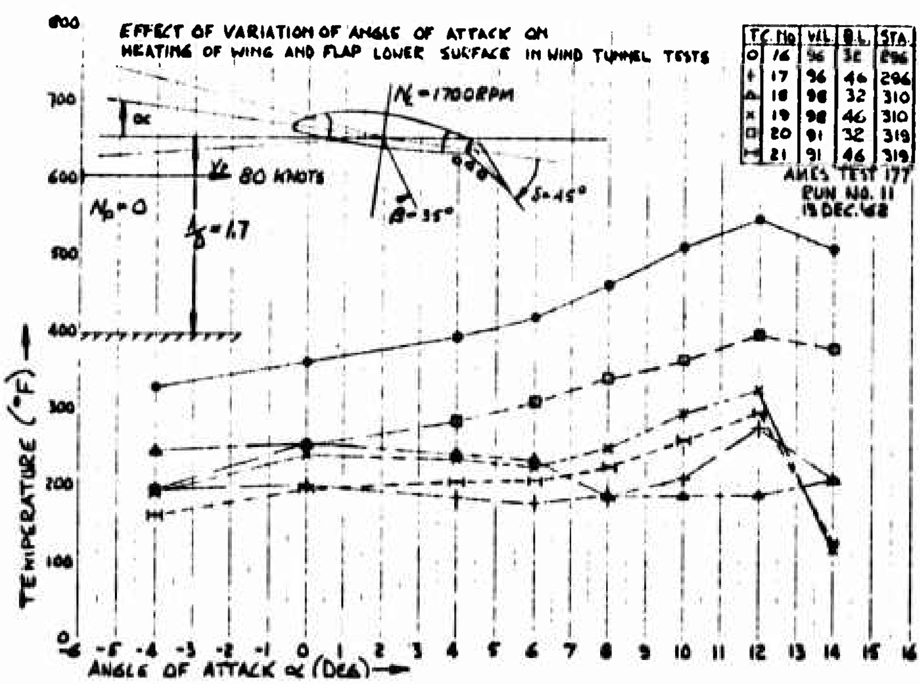


Figure 5.40 Lower Wing and Flap Environment vs Louver Angle: $V_p = 60$ Knots, $\alpha = 0°$, $h/D = 1.7$



	T.C. No.	W.L.	B.L.	STA.
○	16	96	32	296
+	17	96	46	296
△	18	98	32	310
×	19	98	46	310
◻	20	91	32	319
⊢	21	91	46	319

Figure 5.41 Lower Wing and Flap Environment vs Louver Angle: V_p = 80 Knots, $\alpha = 0°$, h/D = 1.7



	T.C. No.	W.L.	B.L.	STA.
○	16	96	32	296
+	17	96	46	296
△	18	98	32	310
×	19	98	46	310
◻	20	91	32	319
⊢	21	91	46	319

Figure 5.42 Lower Wing and Flap Environment vs Angle of Attack: V_p = 80 Knots, $\beta_V = 35°$, h/D = 1.7

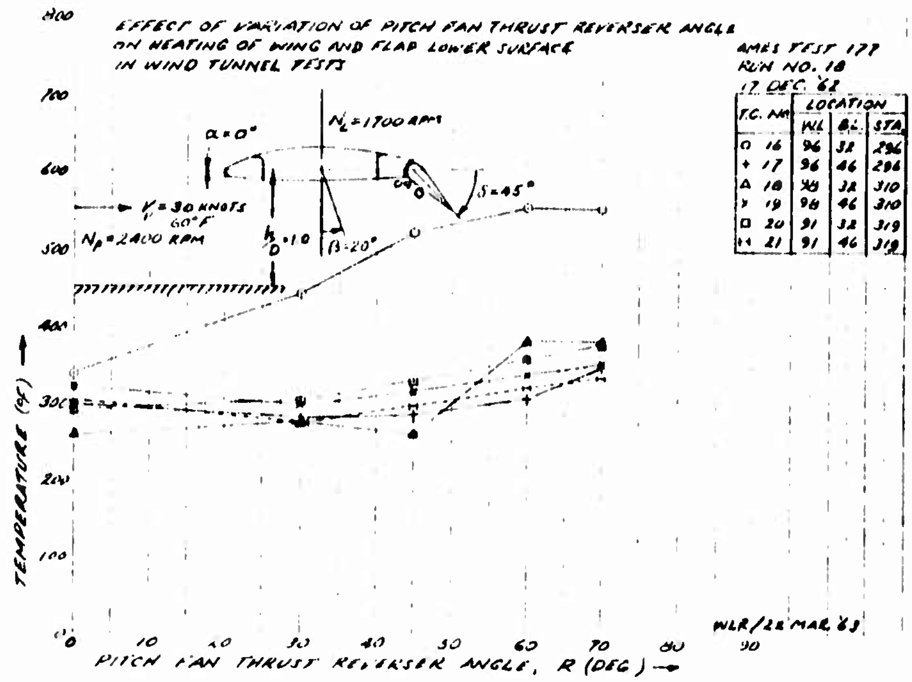


Figure 5.43 Lower Wing and Flap Environment vs Pitch Fan Thrust Reverser Angle: V_p = 30 Knots, $\alpha = 0°$, $\beta_v = 20°$, h/D = 1.0

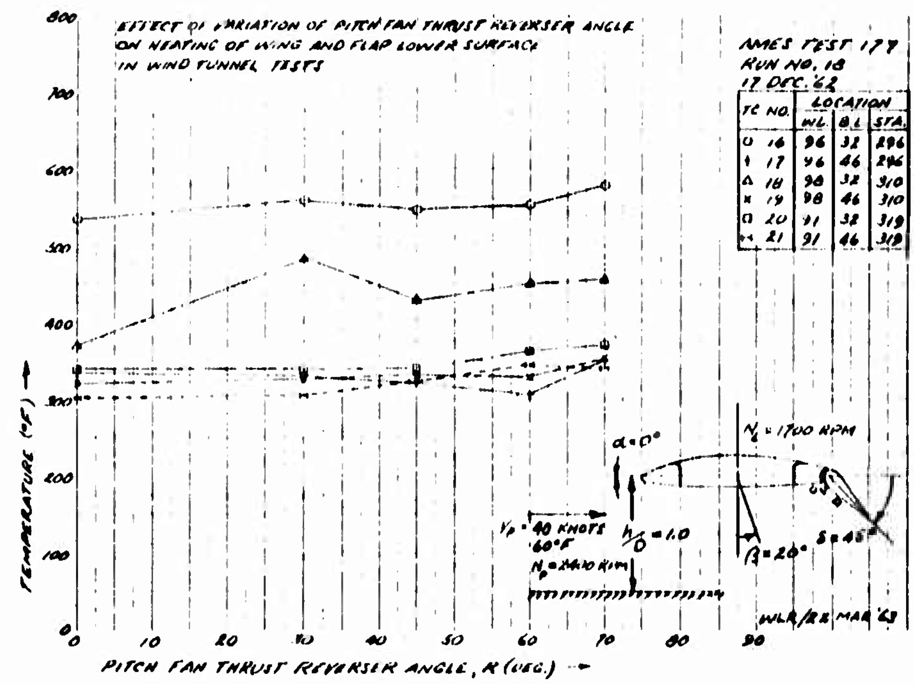


Figure 5.44 Lower Wing and Flap Environment vs Pitch Fan Thrust Reverser Angle: V_p = 40 Knots, $\alpha = 0°$, $\beta_v = 20°$, h/D = 1.0

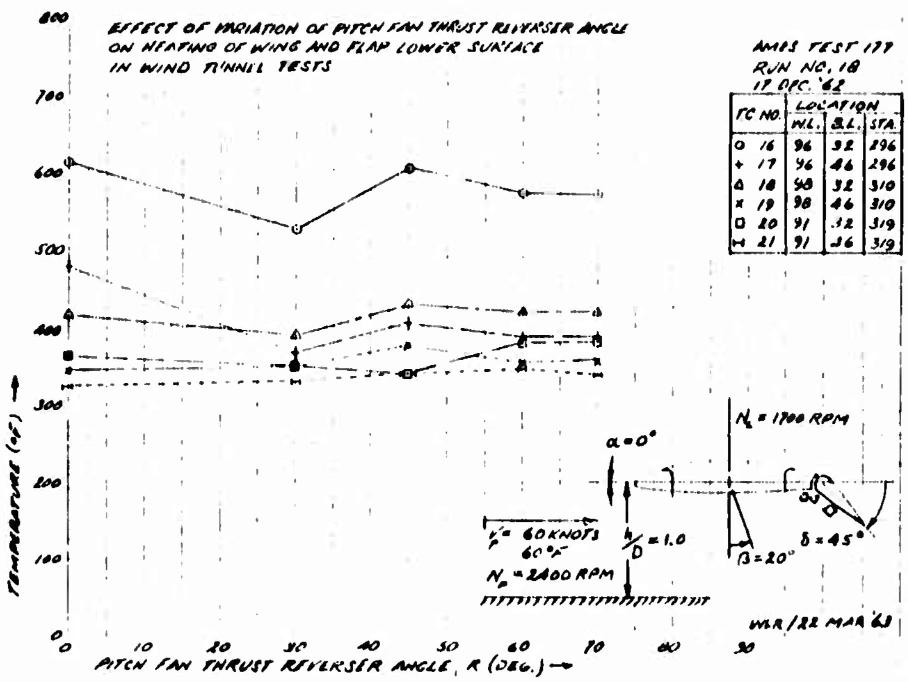


Figure 5.45 Lower Wing and Flap Environment vs Pitch Fan Thrust Reverser Angle: V_p = 60 Knots, α = 0°, β_V = 20°, h/D = 1.0

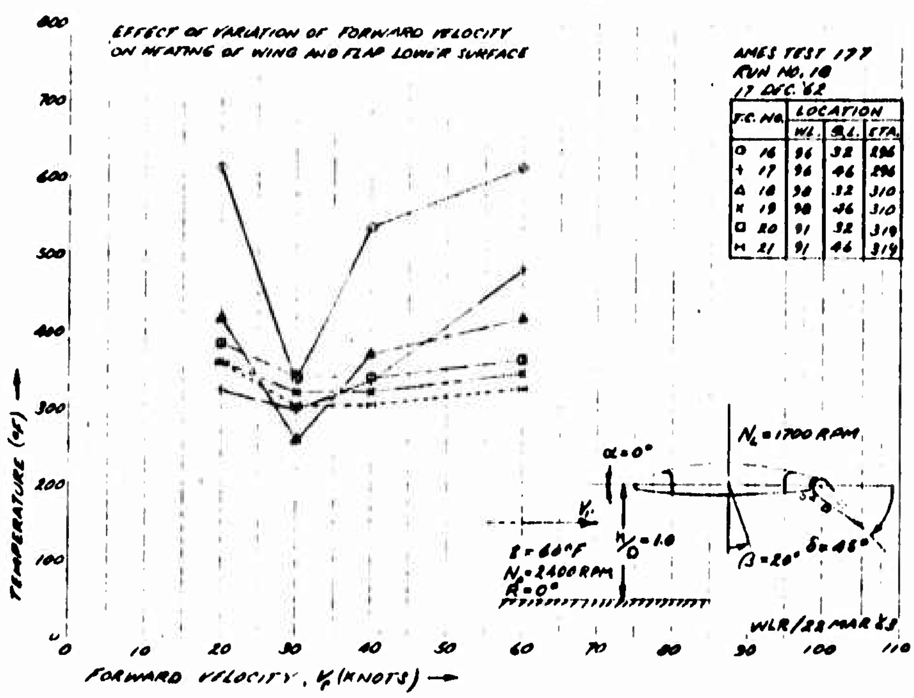


Figure 5.46 Lower Wing and Flap Environment vs Aircraft Velocity: α = 0°, β_V = 20°, h/D = 1.0

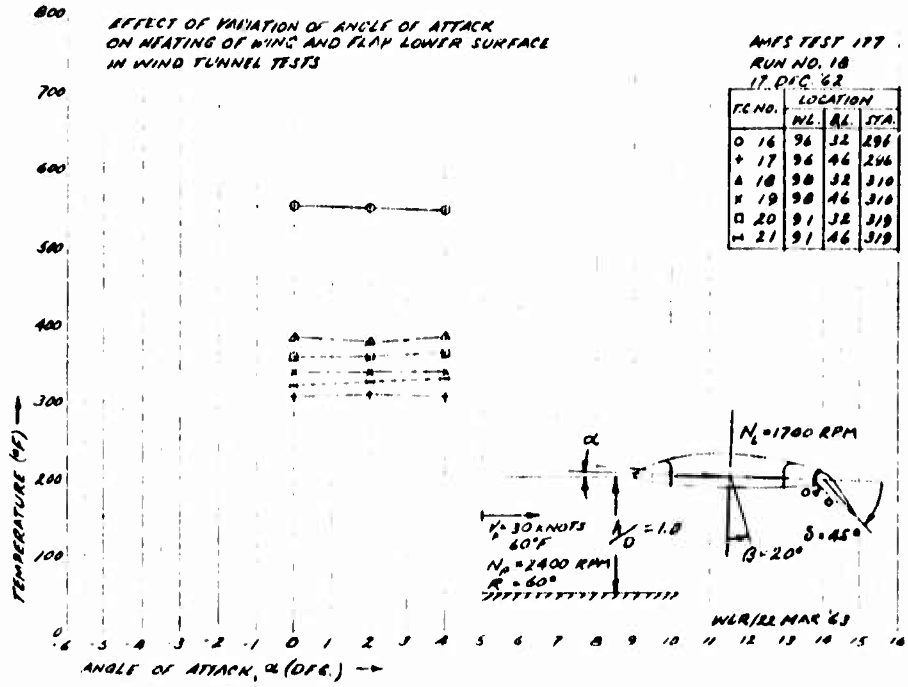


Figure 5.47 Lower Wing and Flap Environment vs Angle of Attack: V_p = 30 Knots, $\beta_V = 20°$, h/D = 1.0

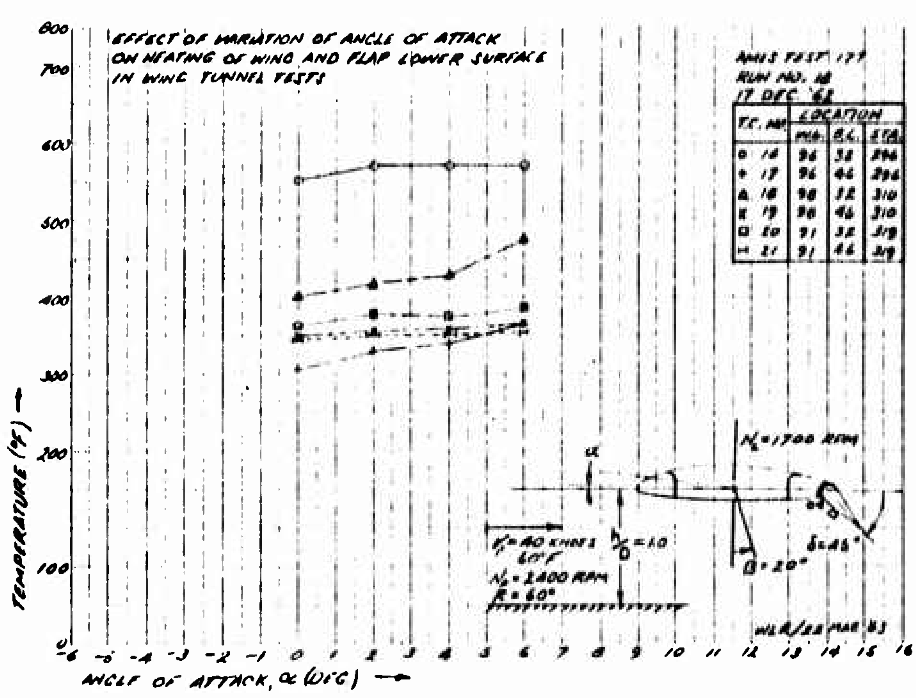


Figure 5.48 Lower Wing and Flap Environment vs Angle of Attack: V_p = 40 Knots, $\beta_V = 20°$, h/D = 1.0

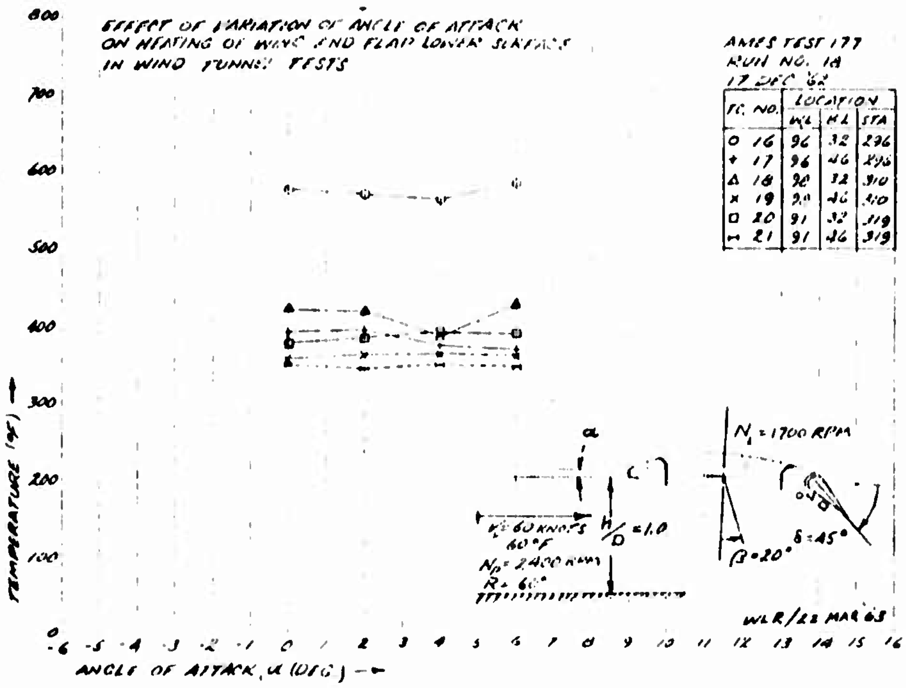


Figure 5.49 Lower Wing and Flap Environment vs Angle of Attack: V_p = 60 Knots, β_v = 20°, h/D = 1.0

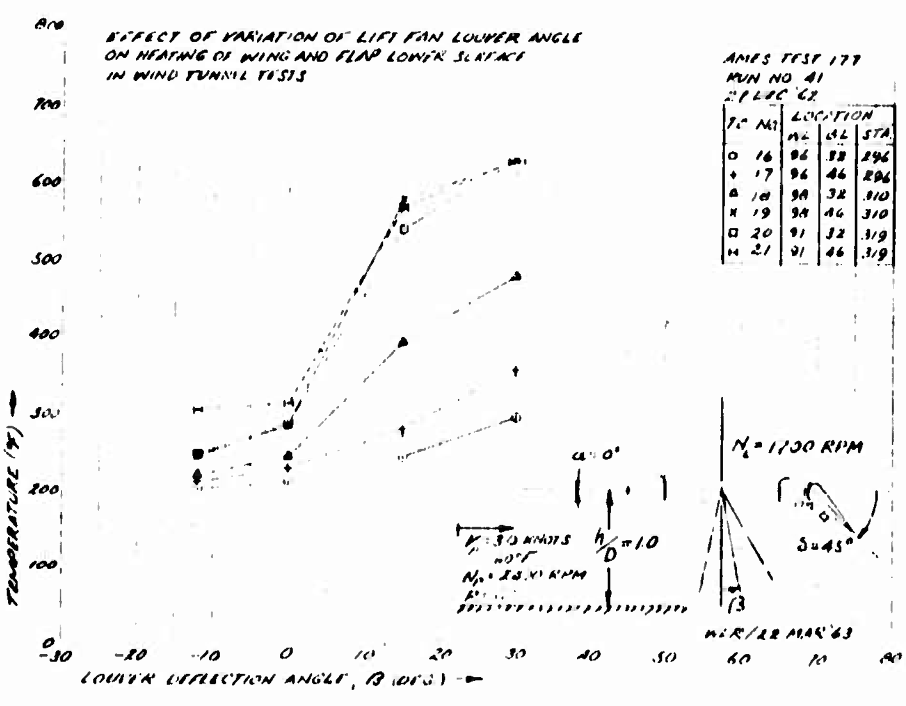


Figure 5.50 Lower Wing and Flap Environment vs Louver Angle: V_p = 30 Knots, α= 0°, h/D = 1.0

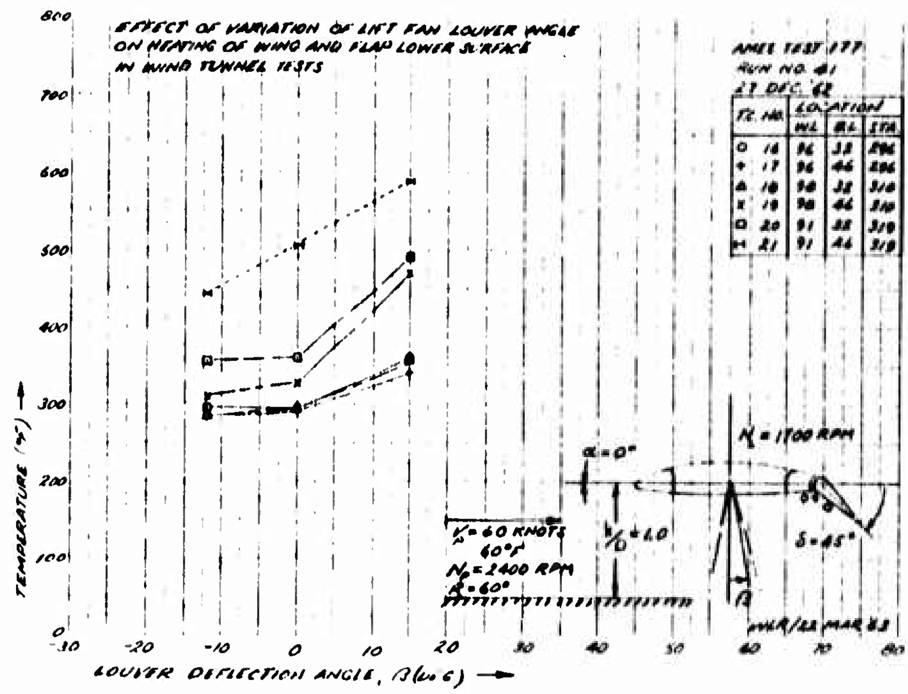


Figure 5.51 Lower Wing and Flap Environment vs Louver Angle: V_p = 60 Knots, α= 0°, h/D = 1.0

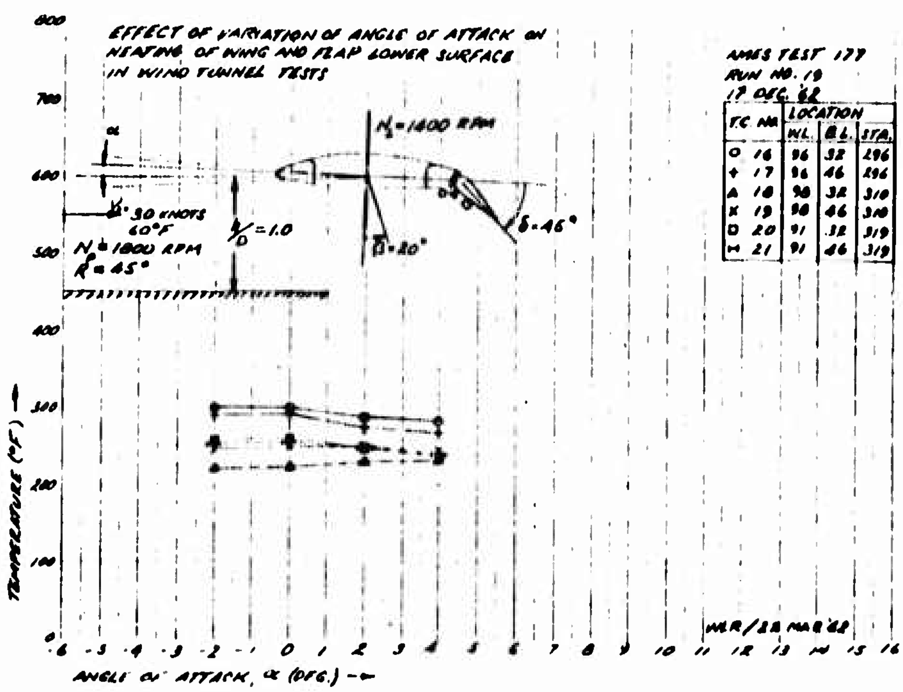


Figure 5.52 Lower Wing and Flap Environment vs Angle of Attack: V_p = 30 Knots, α= 0°, h/P = 1.0

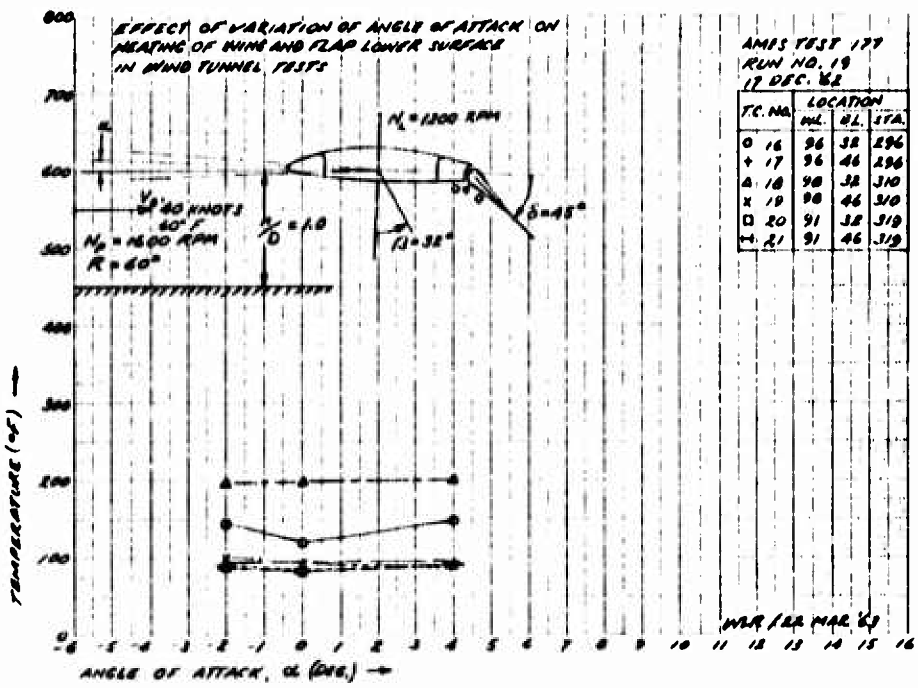


Figure 5.53 Lower Wing and Flap Environment vs Angle of Attack: V_p = 40 Knots, β_v = 32°, h/D = 1.0

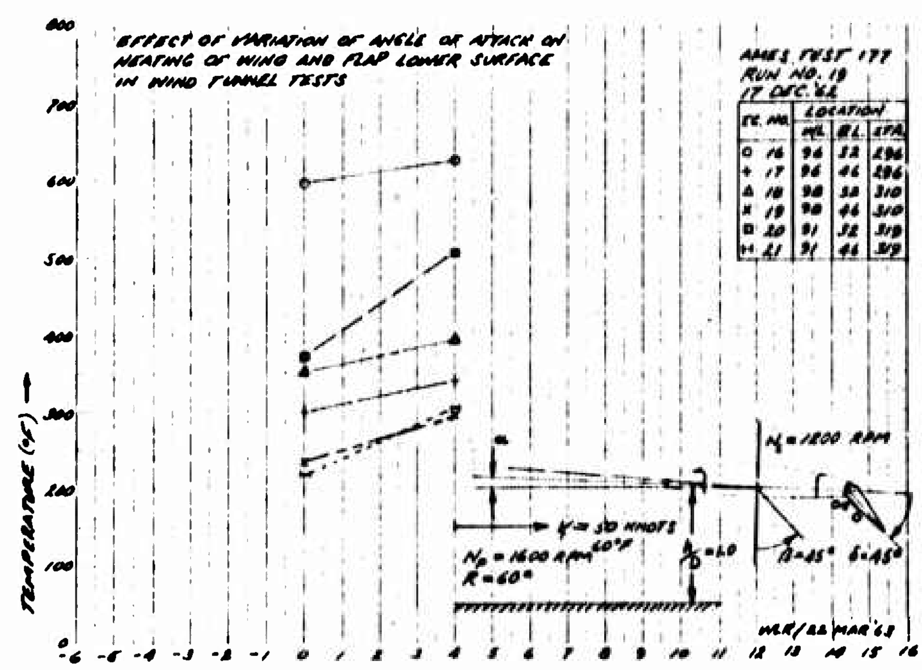


Figure 5.54 Lower Wing and Flap Environment vs Angle of Attack: V_p = 50 Knots, β_v = 45°, h/D = 1.0

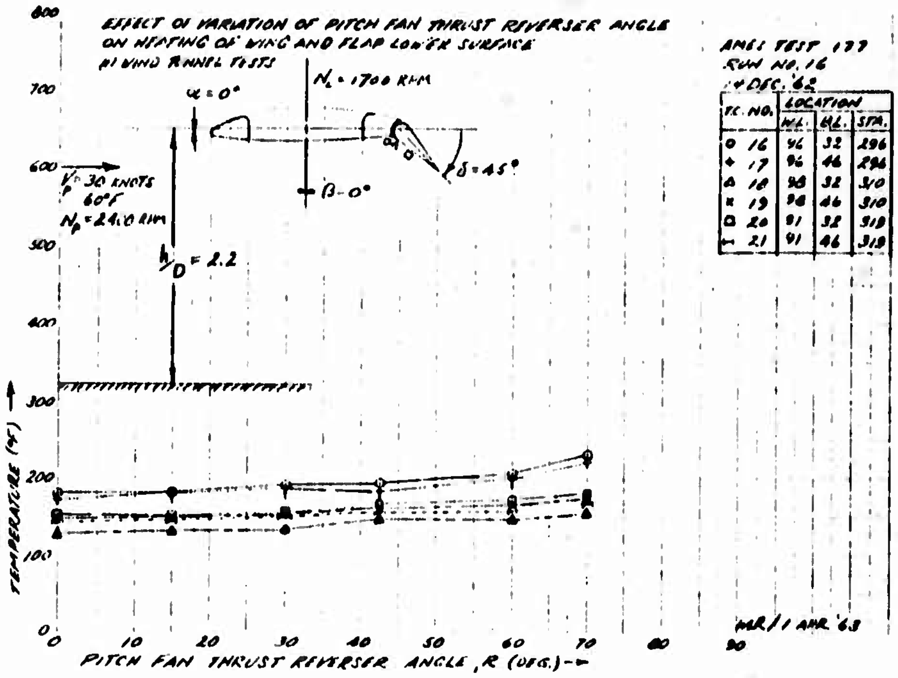


Figure 5.55 Lower Wing and Flap Environment vs Pitch Fan Thrust Reverser Angle: V_p = 30 Knots, α = 0°, β_v = 0°, h/D = 2.2

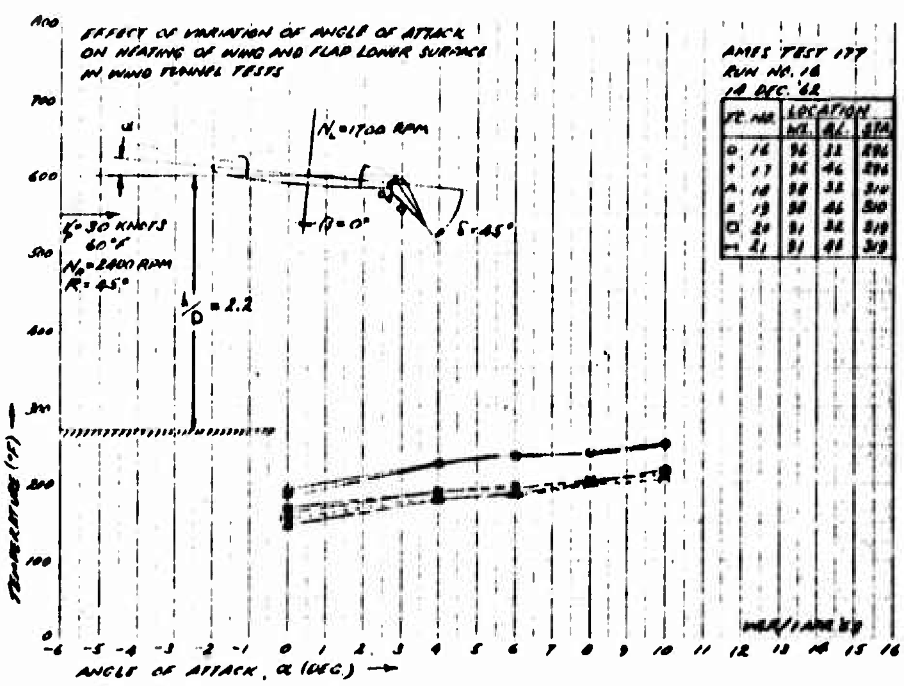


Figure 5.56 Lower Wing and Flap Environment vs Angle of Attack: V_p = 30 Knots, β_v = 0°, h/D = 2.2

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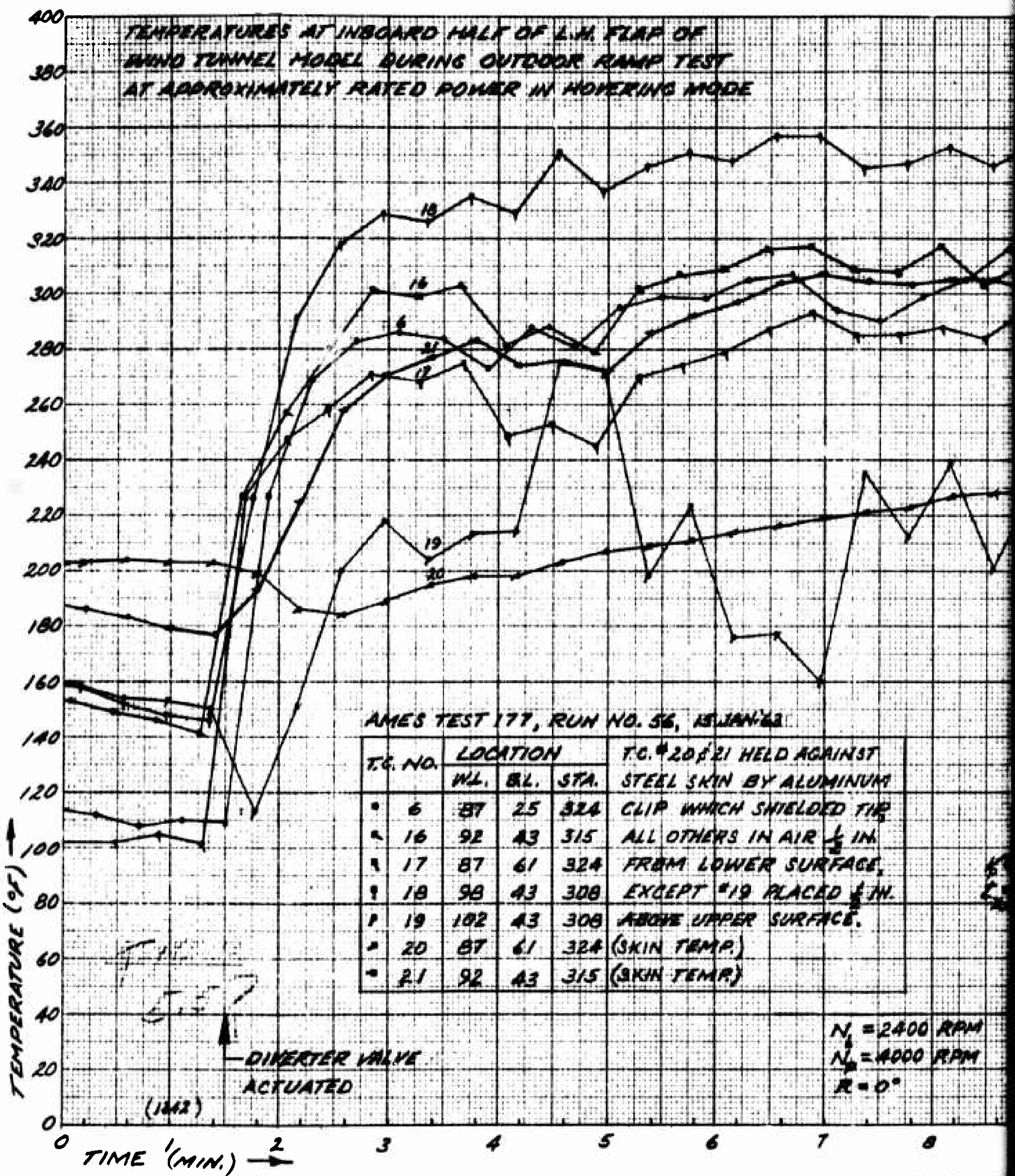

Figure 5. 57 L

A

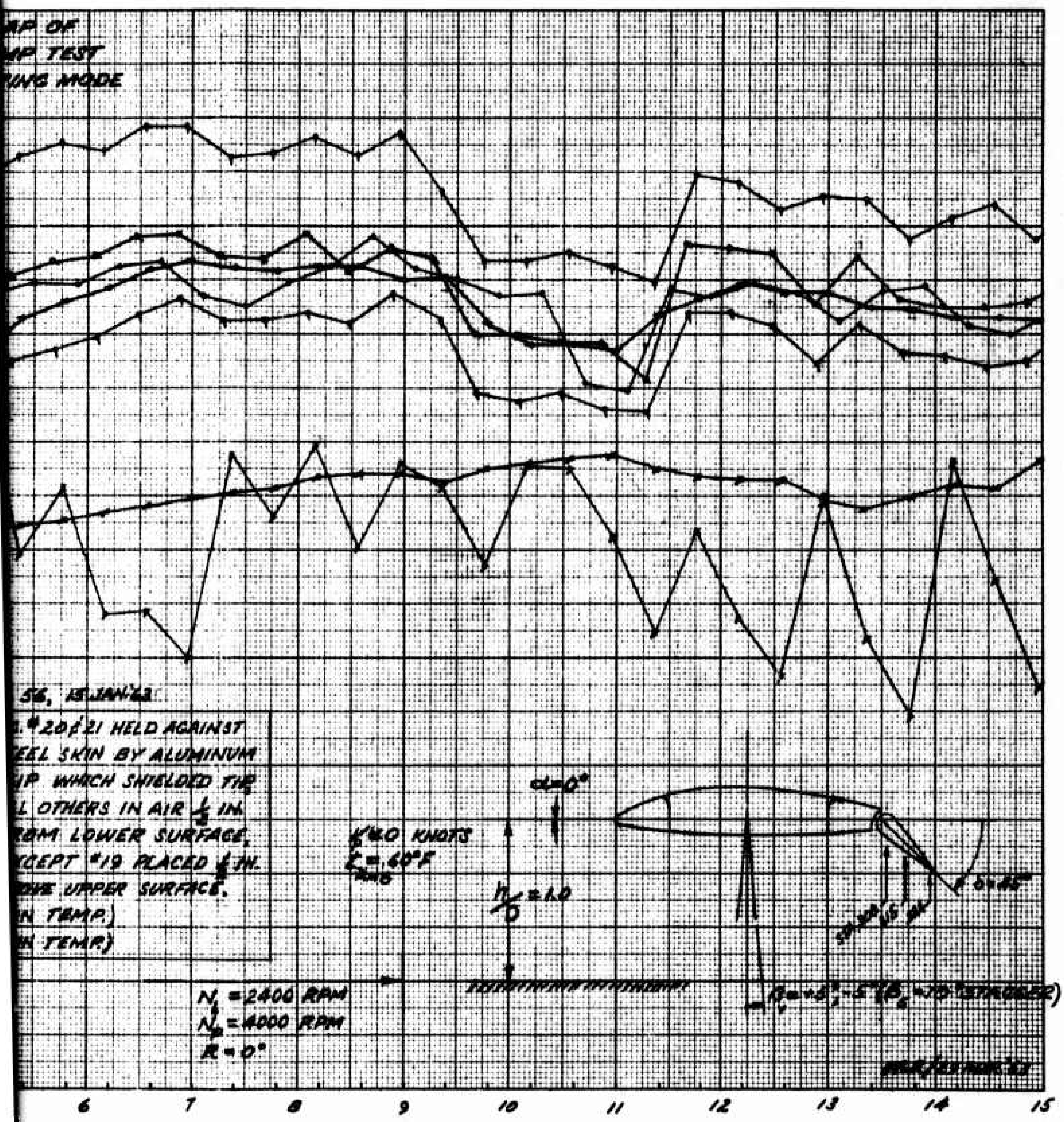

Figure 5.57 Lower Wing and Flap Environment vs Time: V_p = 0 Knots, $\alpha = 0°$, $\beta_V = 0°$, $\beta_S = 10°$, N_F = 2400 RPM

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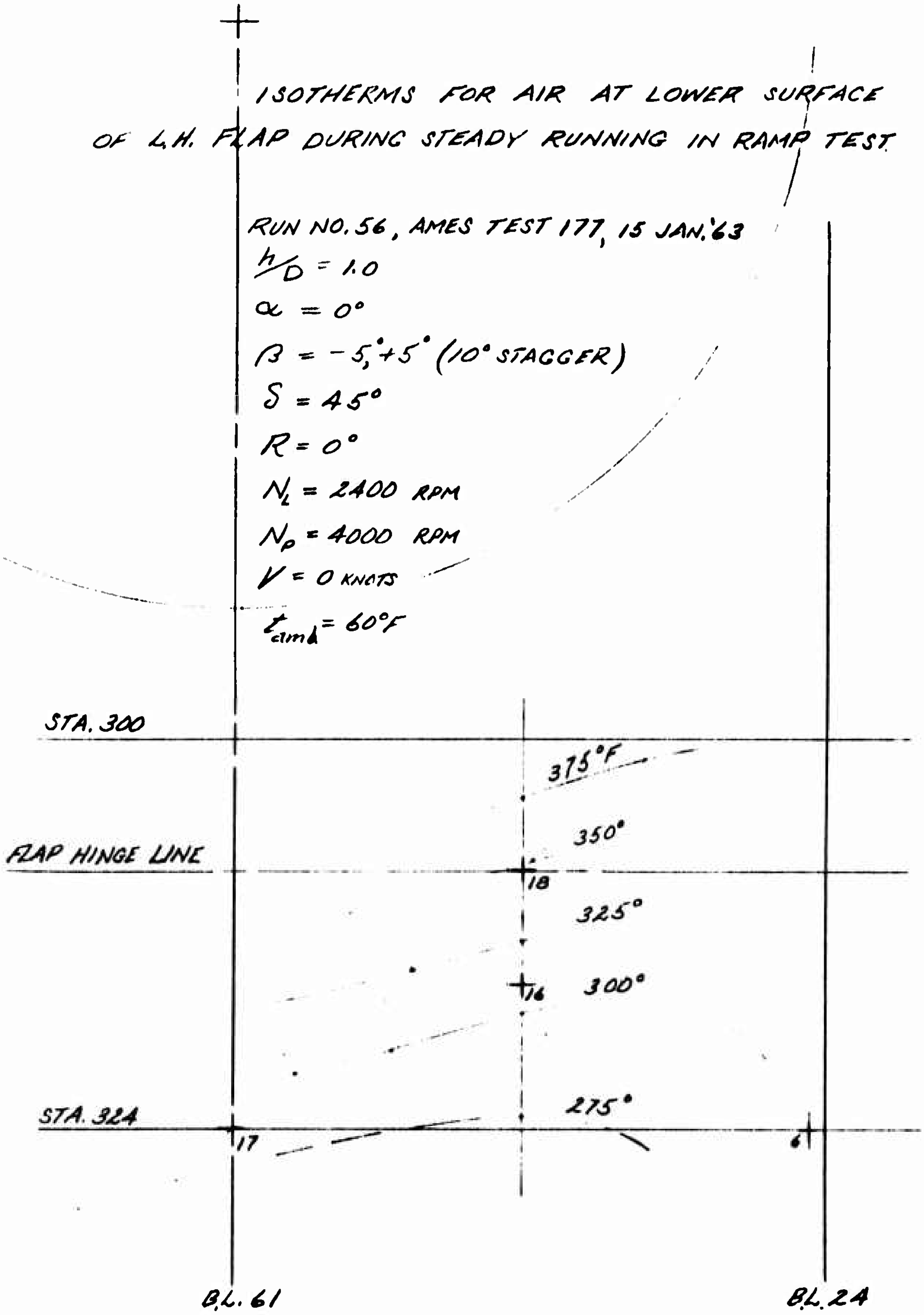

Figure 5.58 Lower Wing and Flap Environment Isotherms: V_p = 0 Knots, $\alpha = 0°$, $\beta_v = 0°$, $\beta_s = 10°$, N_F = 2400 RPM

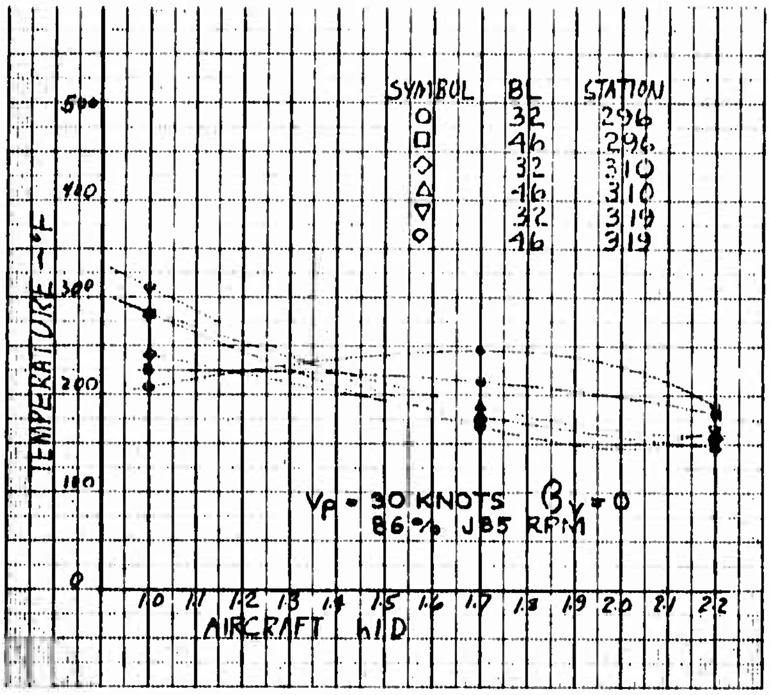

Figure 5.59 Lower Wing and Flap Environment vs h/D: V_p = 30 Knots, $\alpha = 0°$, $\beta_V = 0°$

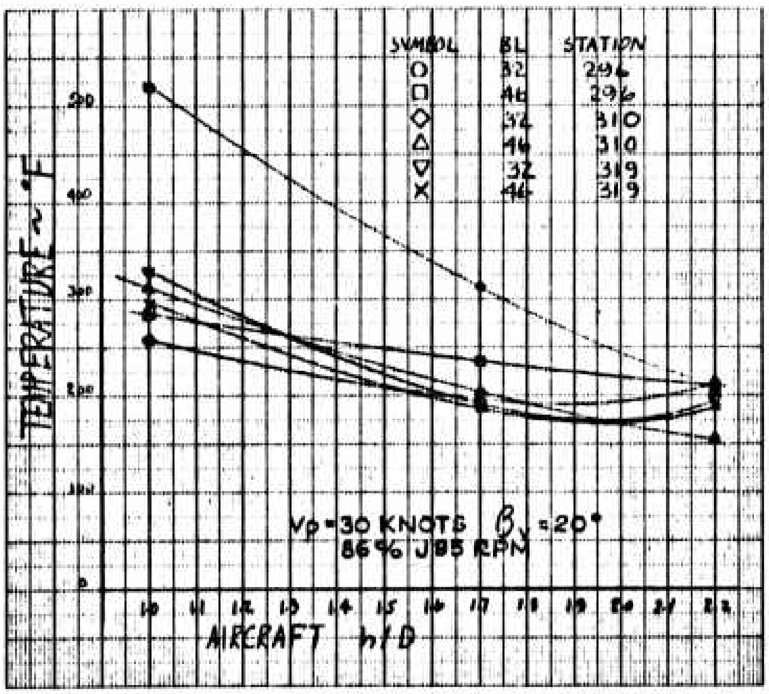

Figure 5.60 Lower Wing and Flap Environment vs h/D: V_p = 30 Knots, $\alpha = 0°$, $\beta_V = 20°$

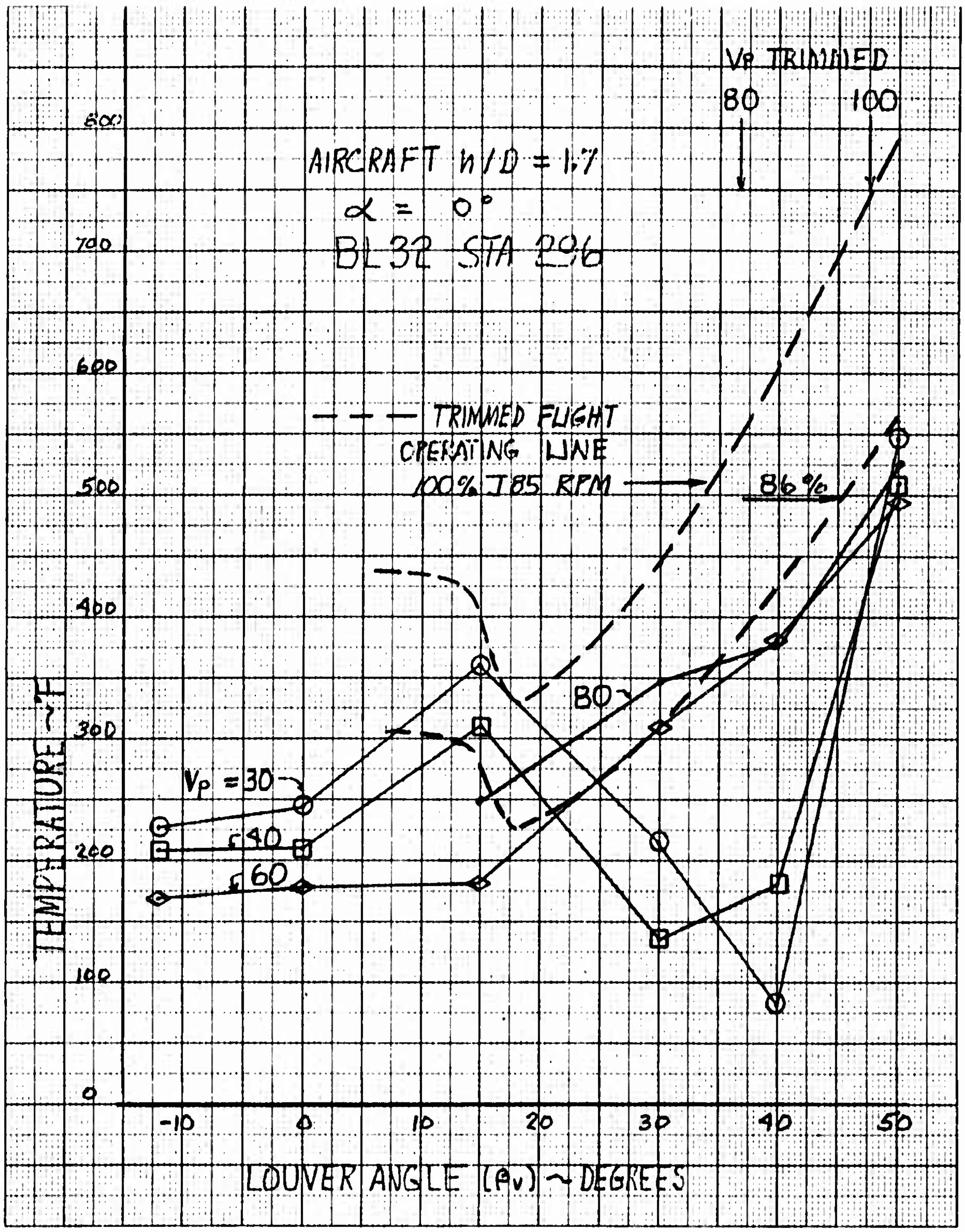

Figure 5.61 **Lower Wing Environment vs Louver Angle and Aircraft Velocity: BL 32, Sta. 296, h/D = 1.7, 86% J85 RPM**

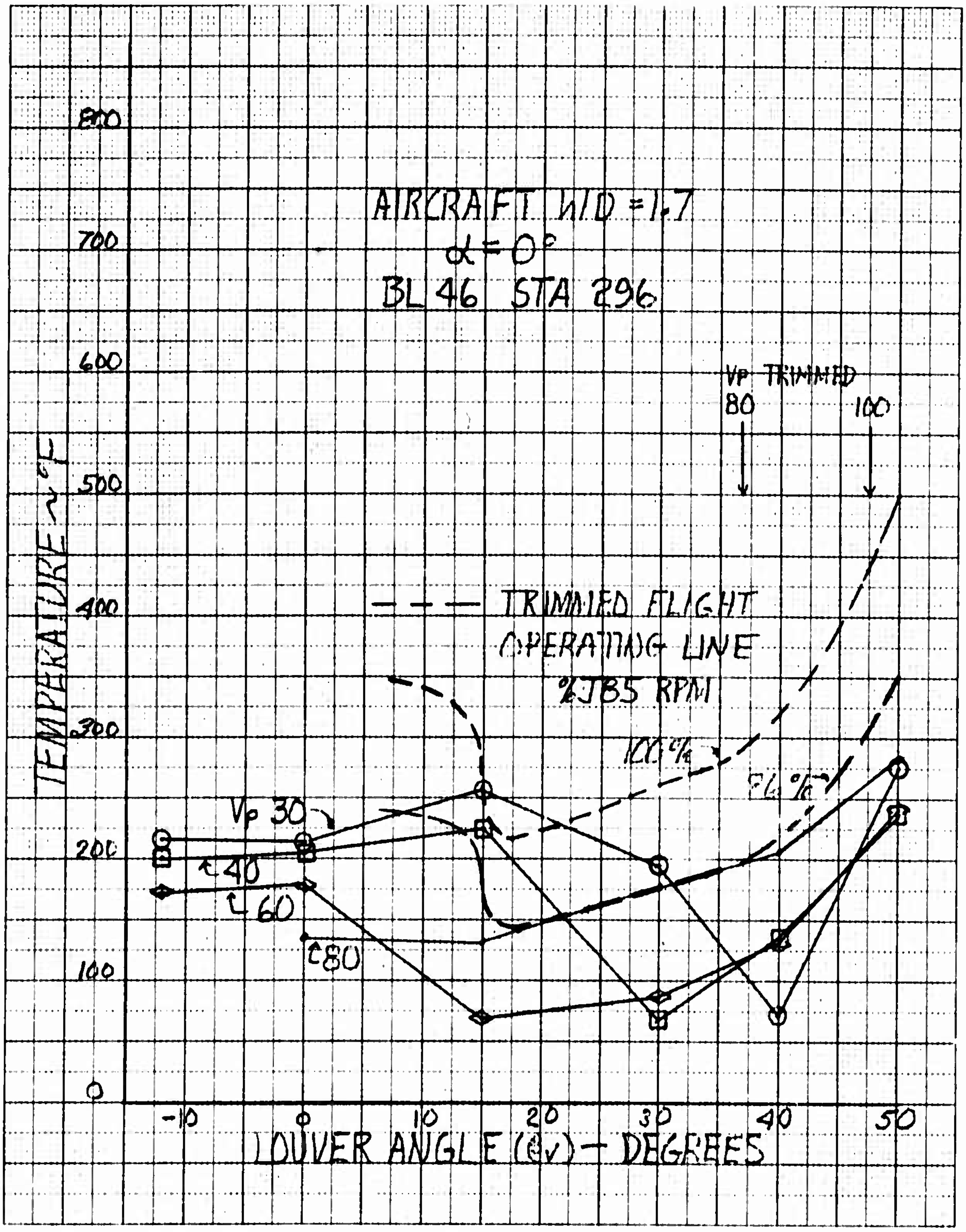

Figure 5.62 **Lower Wing Environment vs Louver Angle and Aircraft Velocity: BL 46, Sta. 296, h/D = 1.7, 86% J85 RPM**

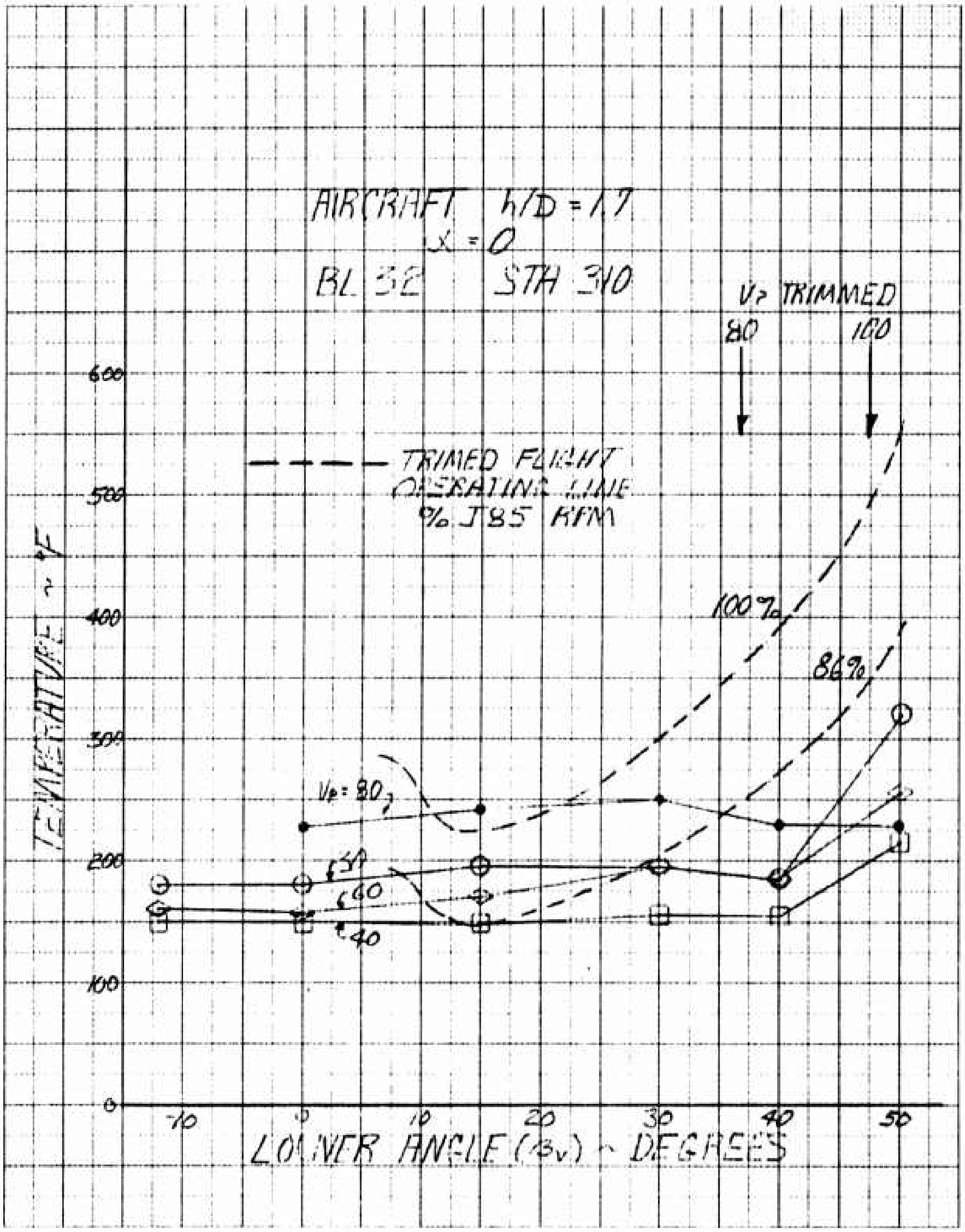

Figure 5.63 Lower Flap Environment vs Louver Angle and Aircraft Velocity: BL 32, Sta. 310, h/D = 1.7, 86% J85 RPM

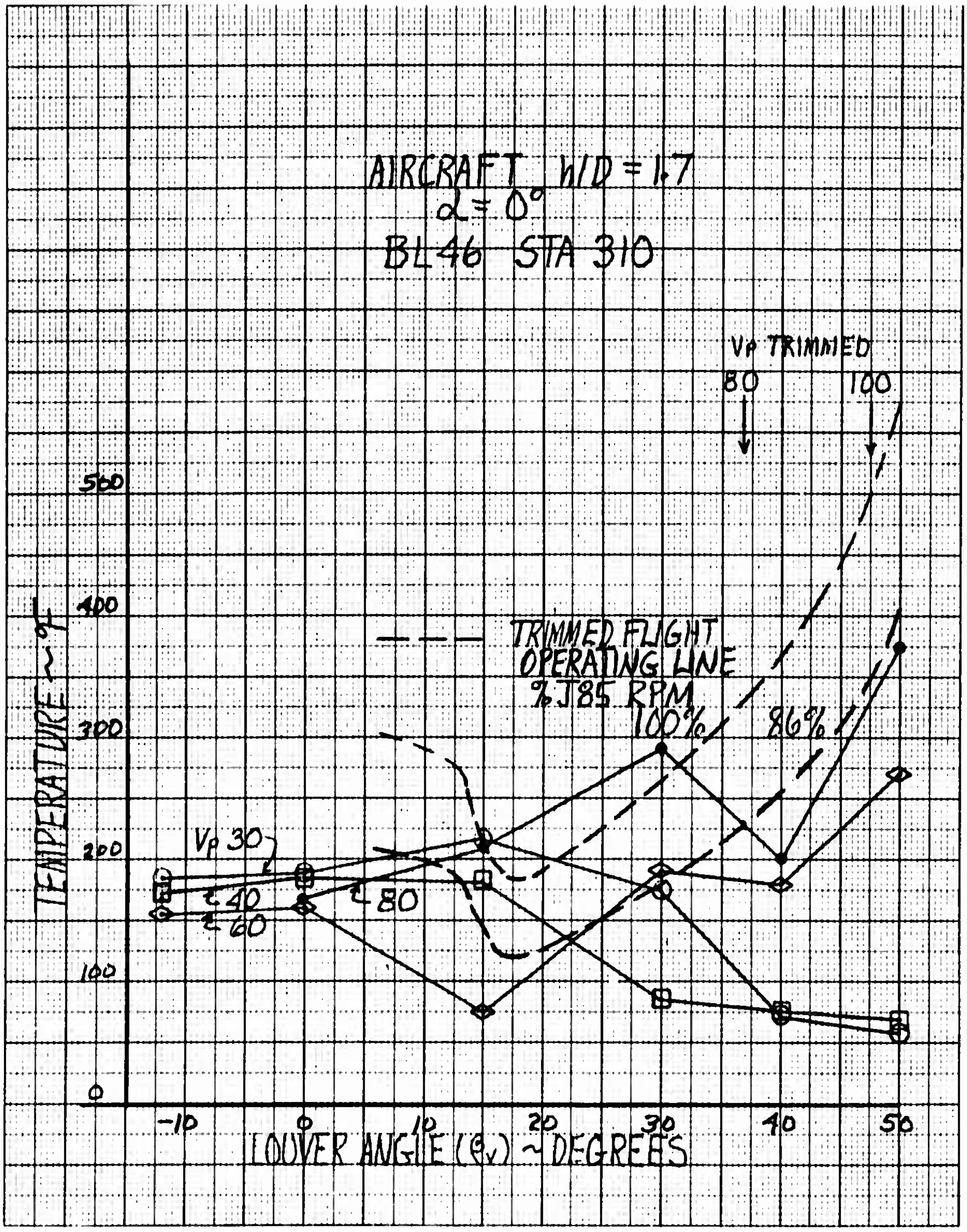

Figure 5.64 Lower Flap Environment vs Louver Angle and Aircraft Velocity: BL 46, Sta. 310, h/D = 1.7, 86% J85 RPM

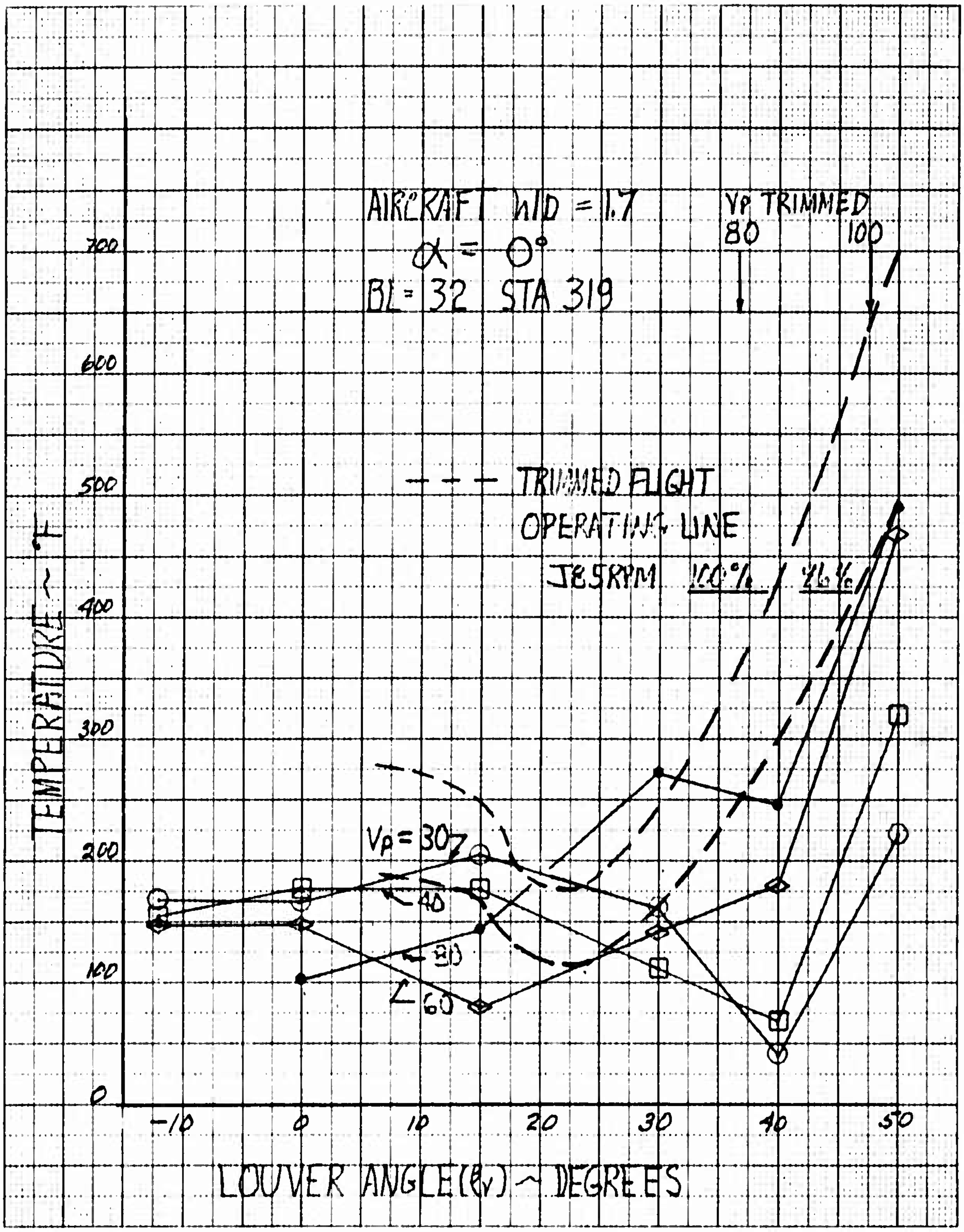

Figure 5.65 Lower Flap Environment vs Louver Angle and Aircraft Velocity: BL 32, Sta. 319, h/D = 1.7, 86% J85 RPM

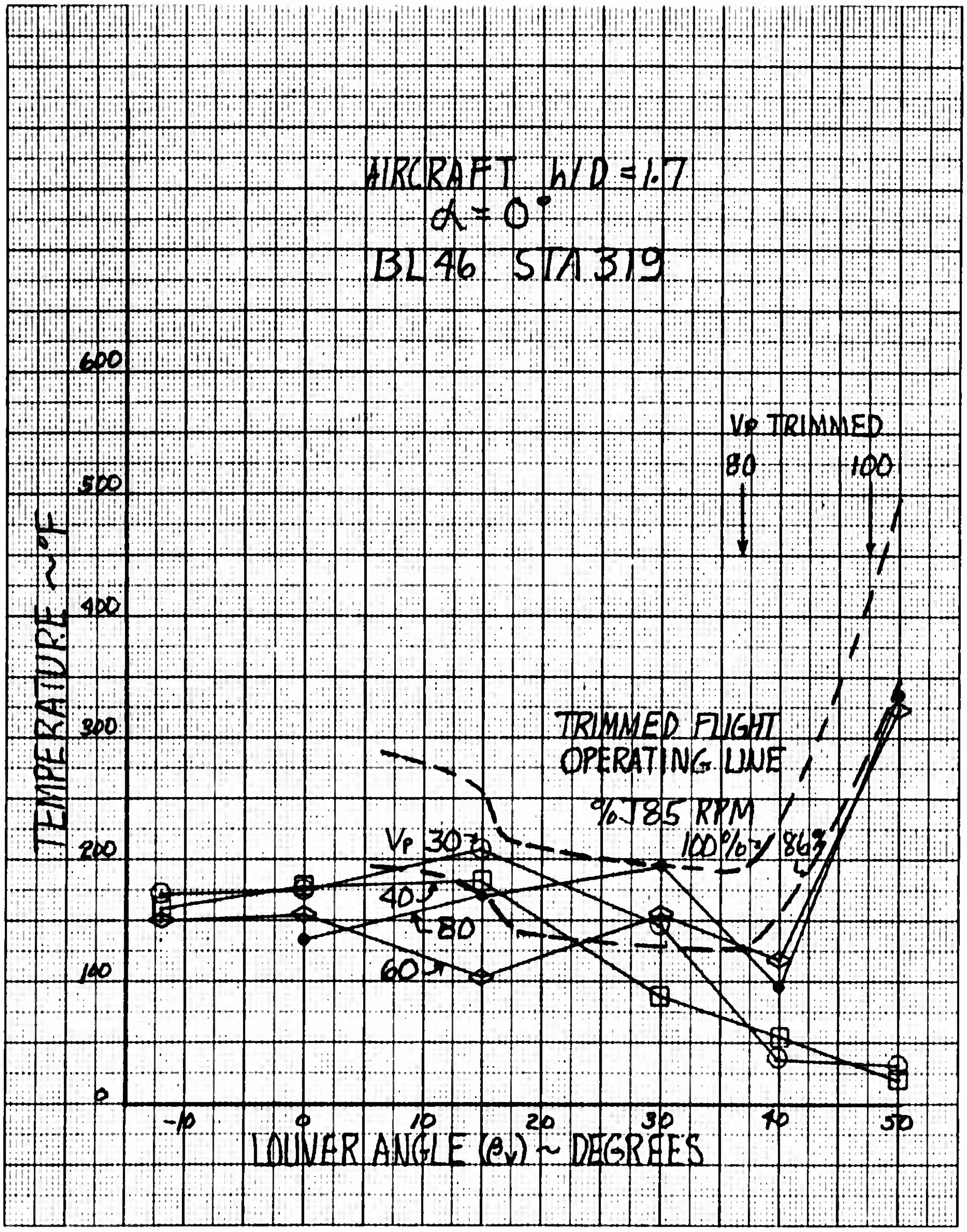

Figure 5.66 **Lower Flap Environment vs Louver Angle and Aircraft Velocity: BL 46, Sta. 319, h/D = 1.7, 86% J85 RPM**

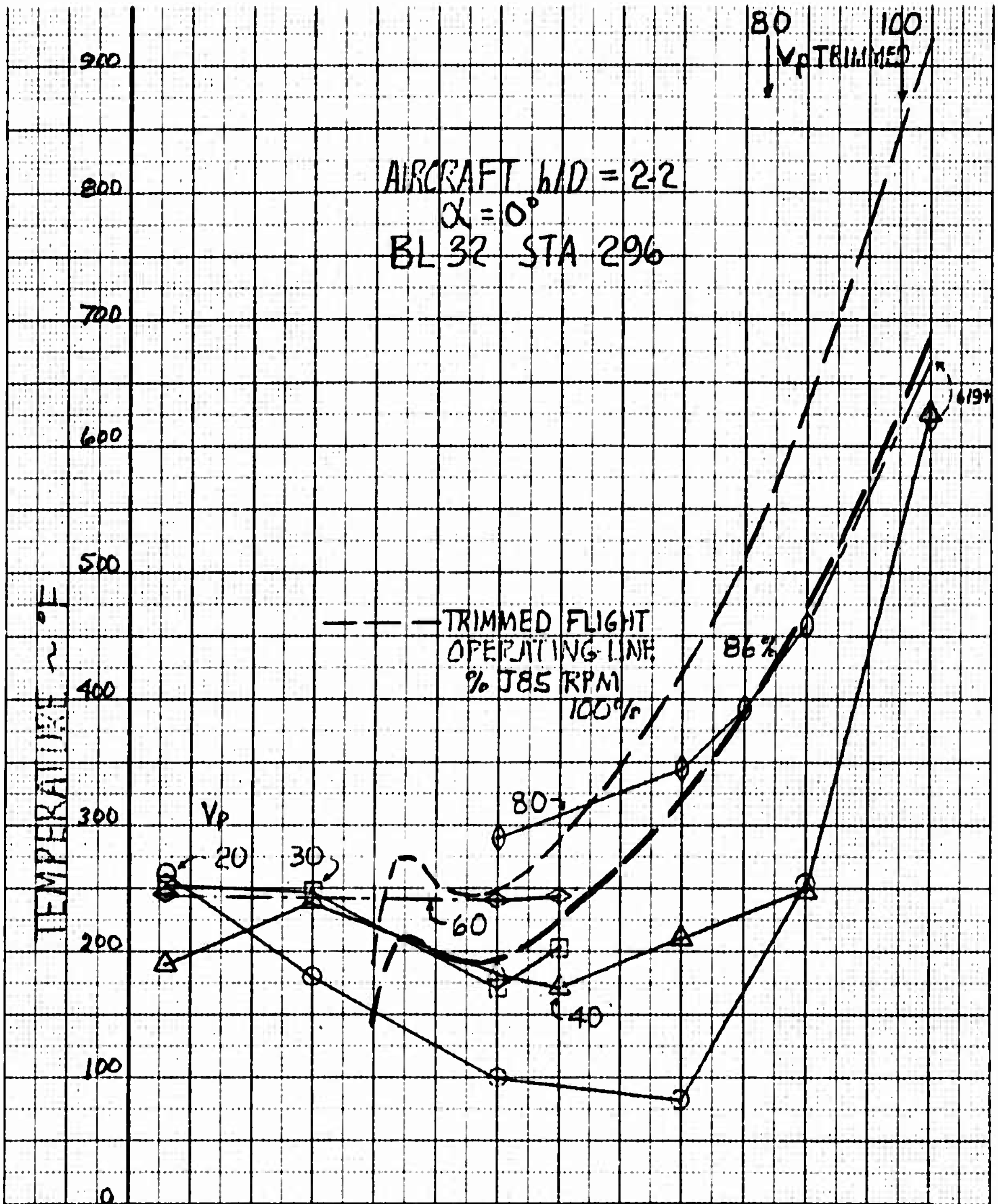

Figure 5.67 Lower Wing Environment vs Louver Angle and Aircraft Velocity: BL 32, Sta. 296, h/D = 2.2, 86% RPM

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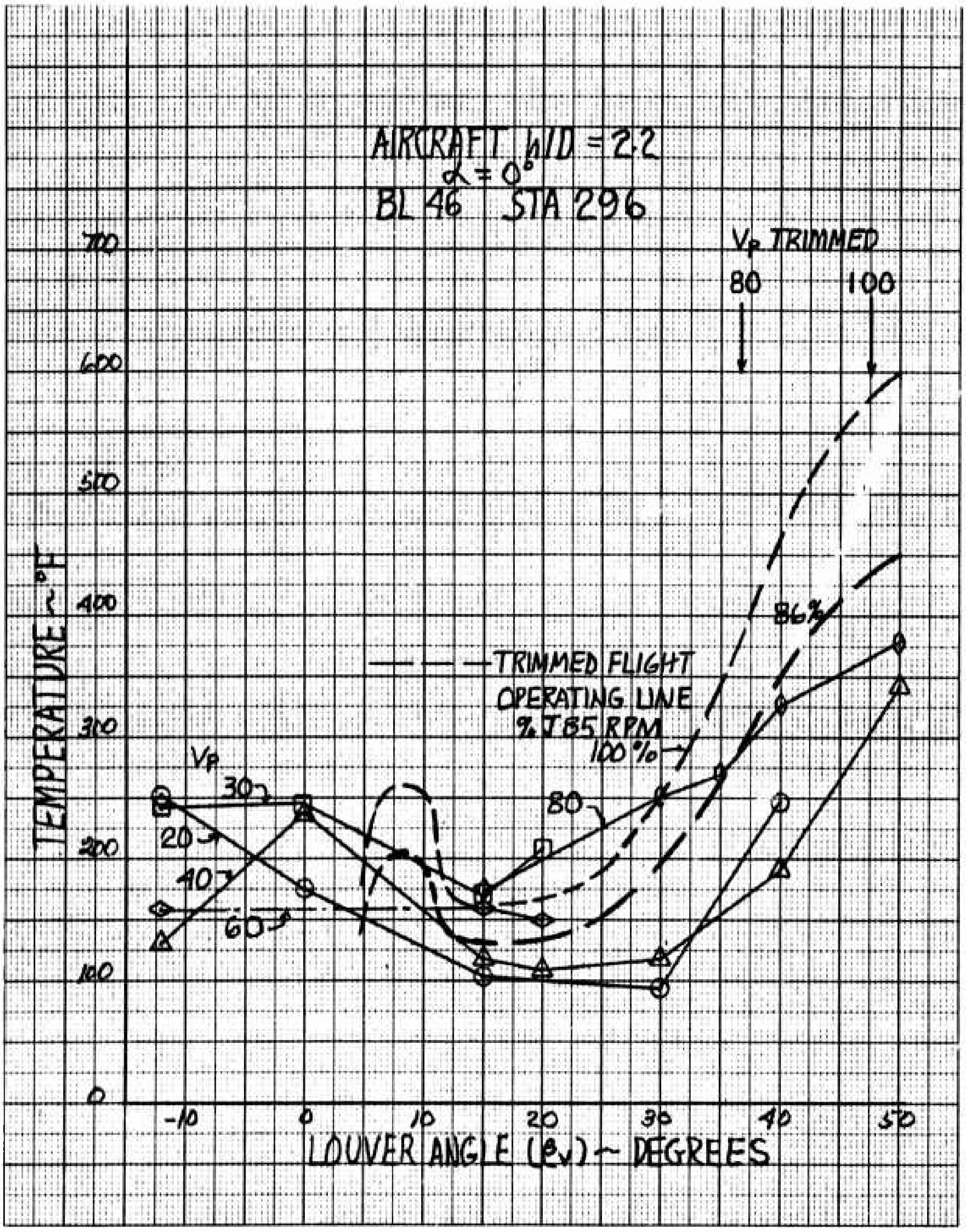

Figure 5.68 **Lower Wing Environment vs Louver Angle and Aircraft Velocity: BL 46, Sta. 296, h/D = 2.2, 86% J85 RPM**

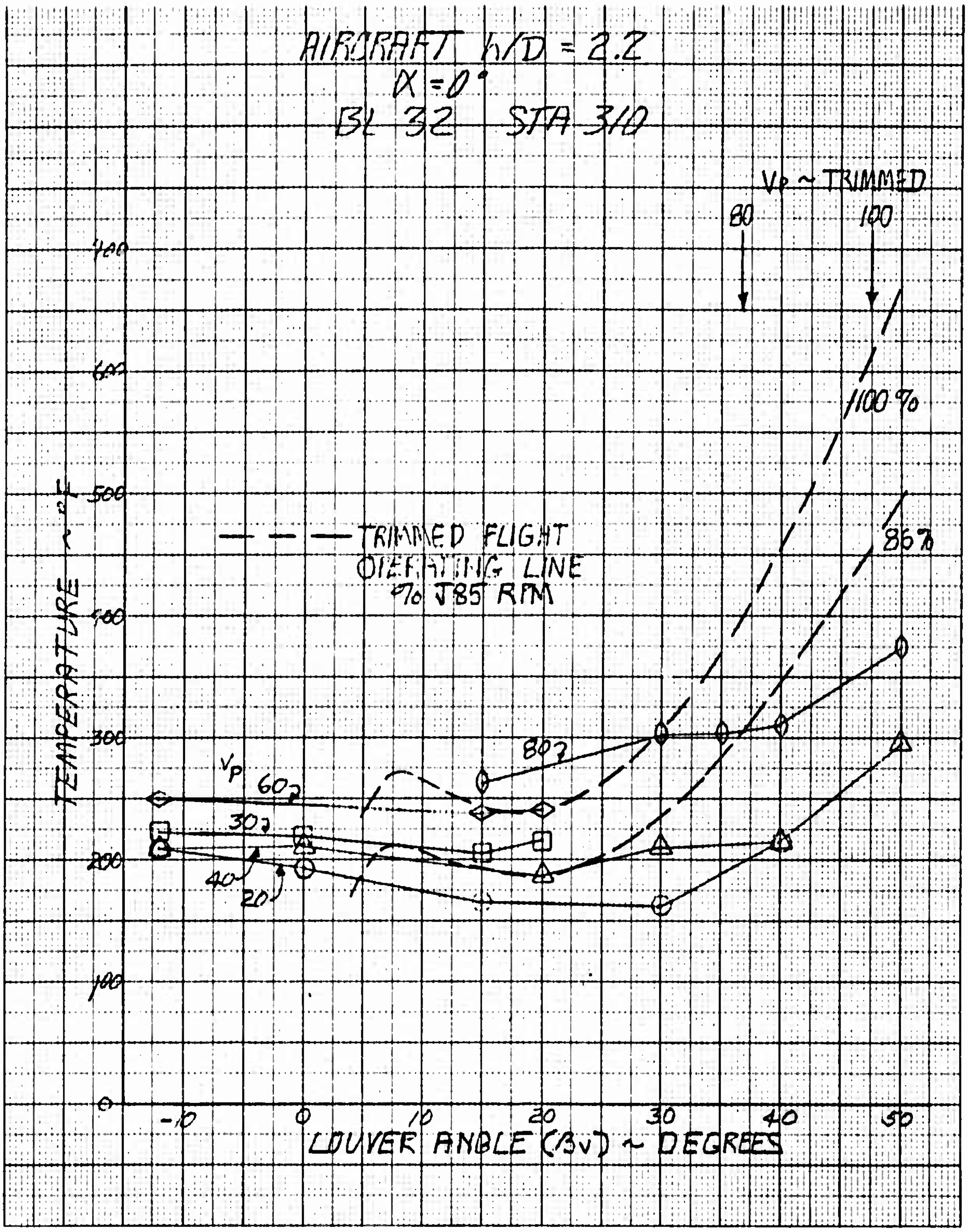

Figure 5.69 Lower Flap Environment vs Louver Angle and Aircraft Velocity: BL 32, Sta. 310, h/D = 2.2, 86% J85 RPM

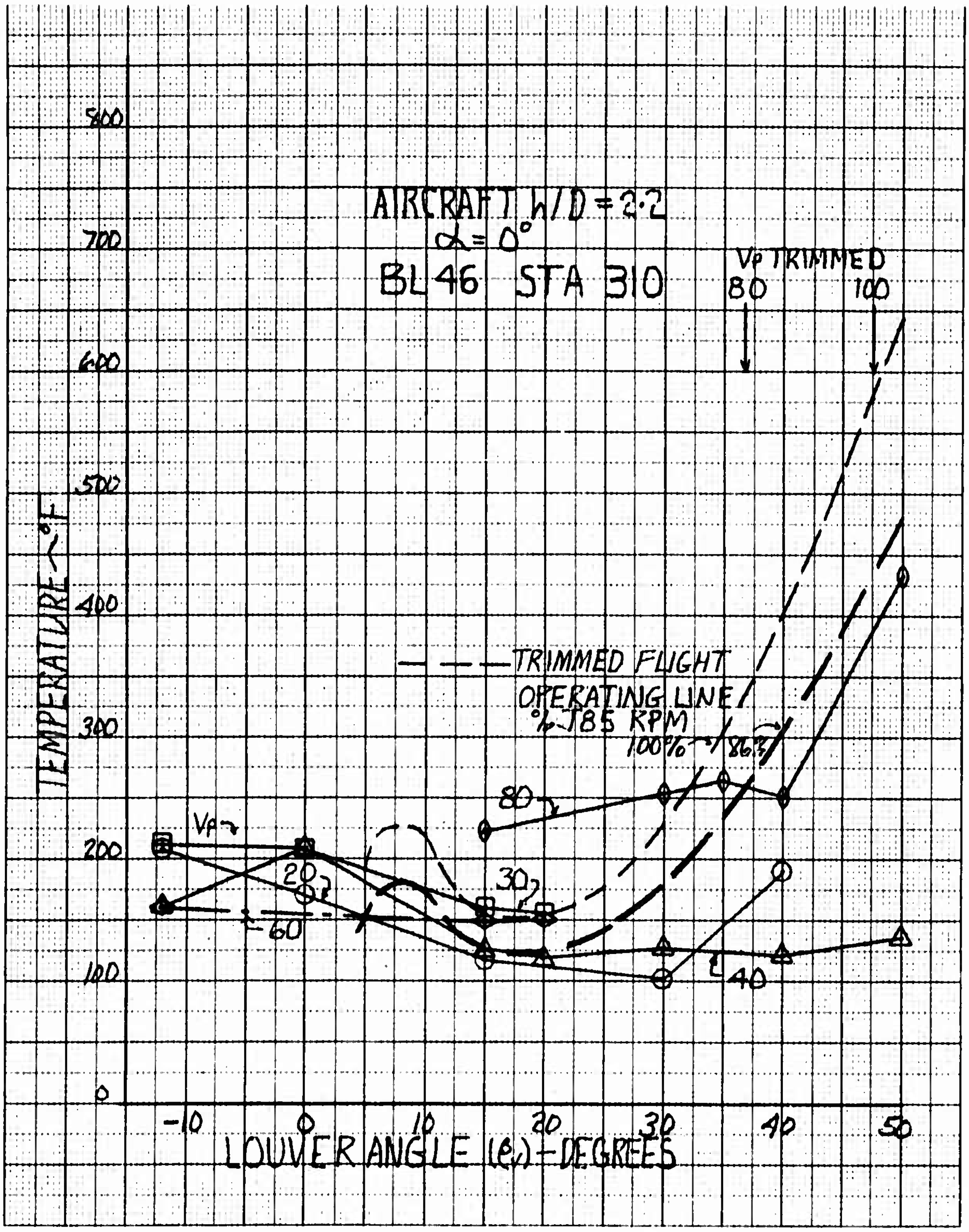

Figure 5.70 Lower Flap Environment vs Louver Angle and Aircraft Velocity: BL 46, Sta. 310, h/D = 2.2, 86% J85 RPM

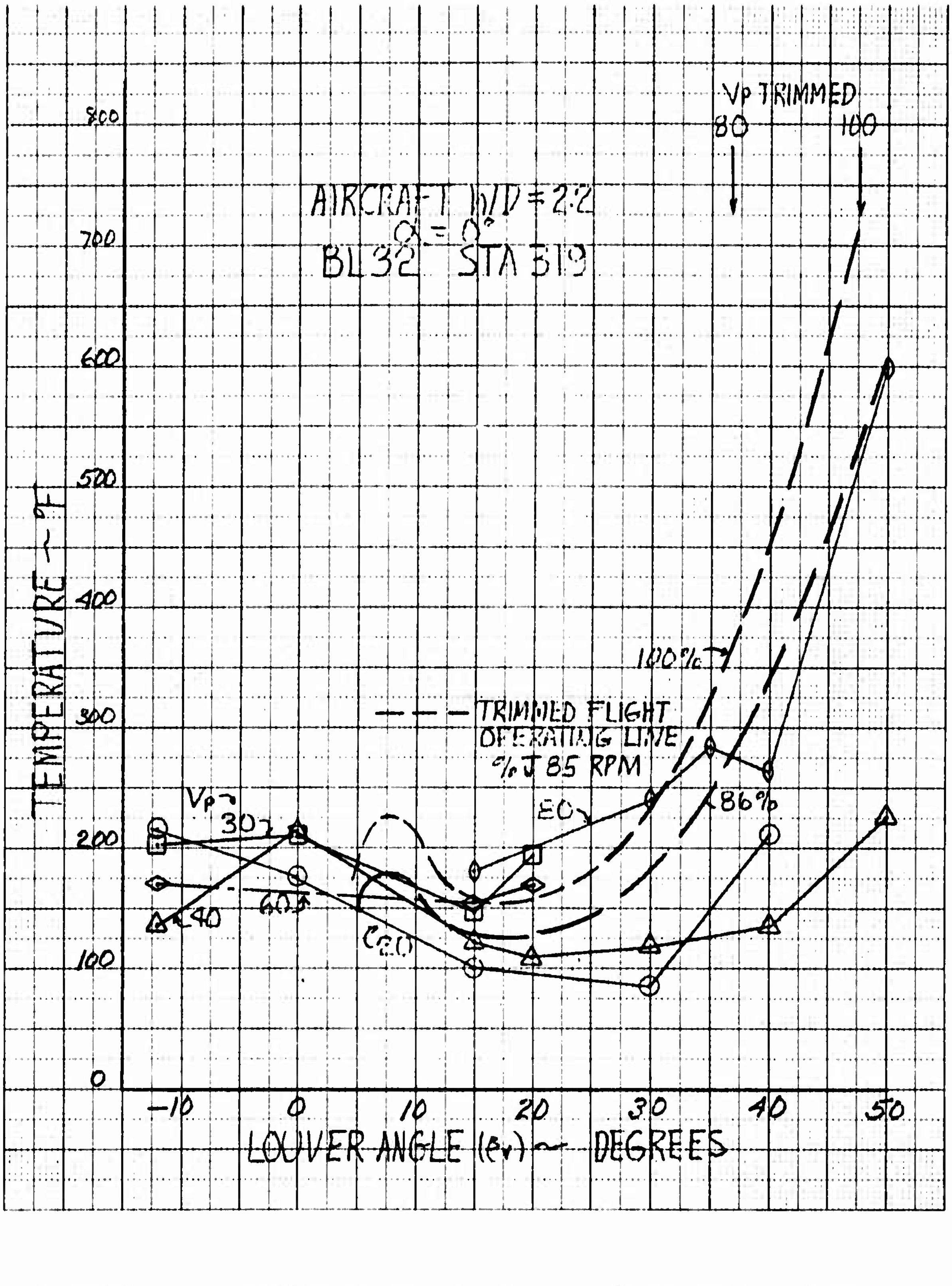

Figure 5.71 Lower Flap Environment vs Louver Angle and Aircraft Velocity: BL 32, Sta. 319, h/D = 2.2, 86% J85 RPM

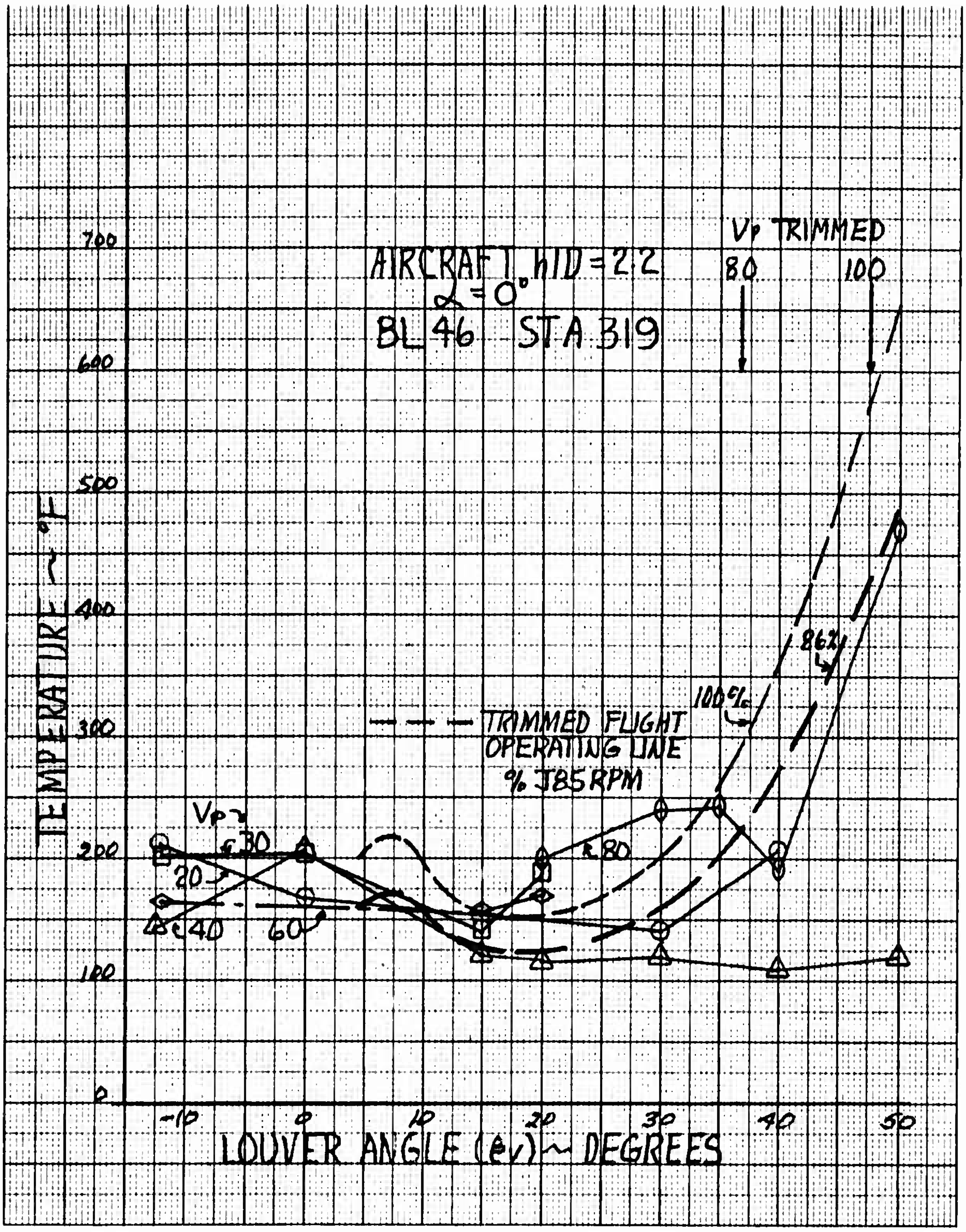

Figure 5.72 Lower Flap Environment vs Louver Angle and Aircraft Velocity: BL 46, Sta. 319, h/D = 2.2, 86% J85 RPM

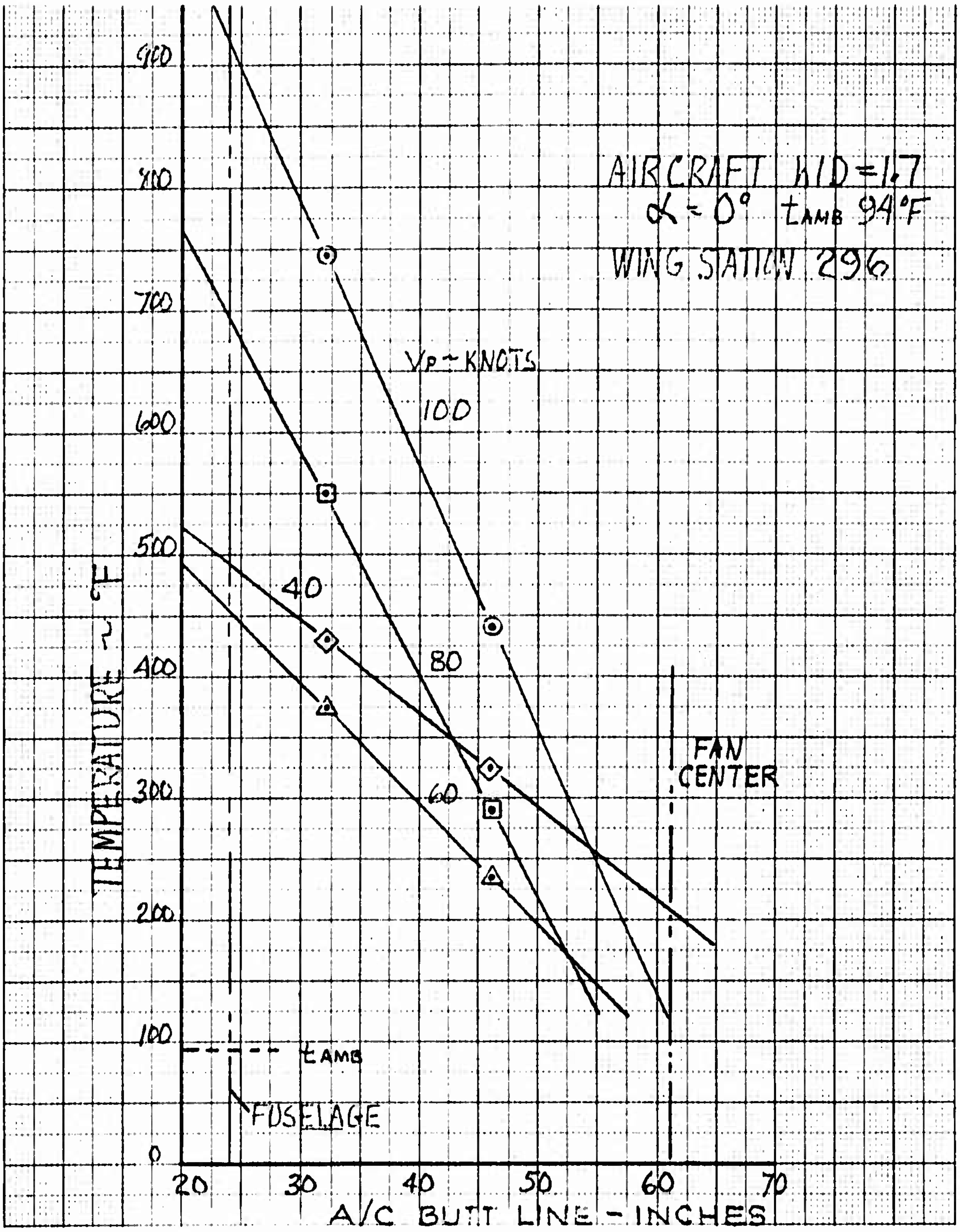

Figure 5.73 Spanwise Distribution of Estimated Trimmed Flight Lower Wing Environment vs Aircraft Velocity: Sta. 296, 100% J85 RPM, h/D = 1.7

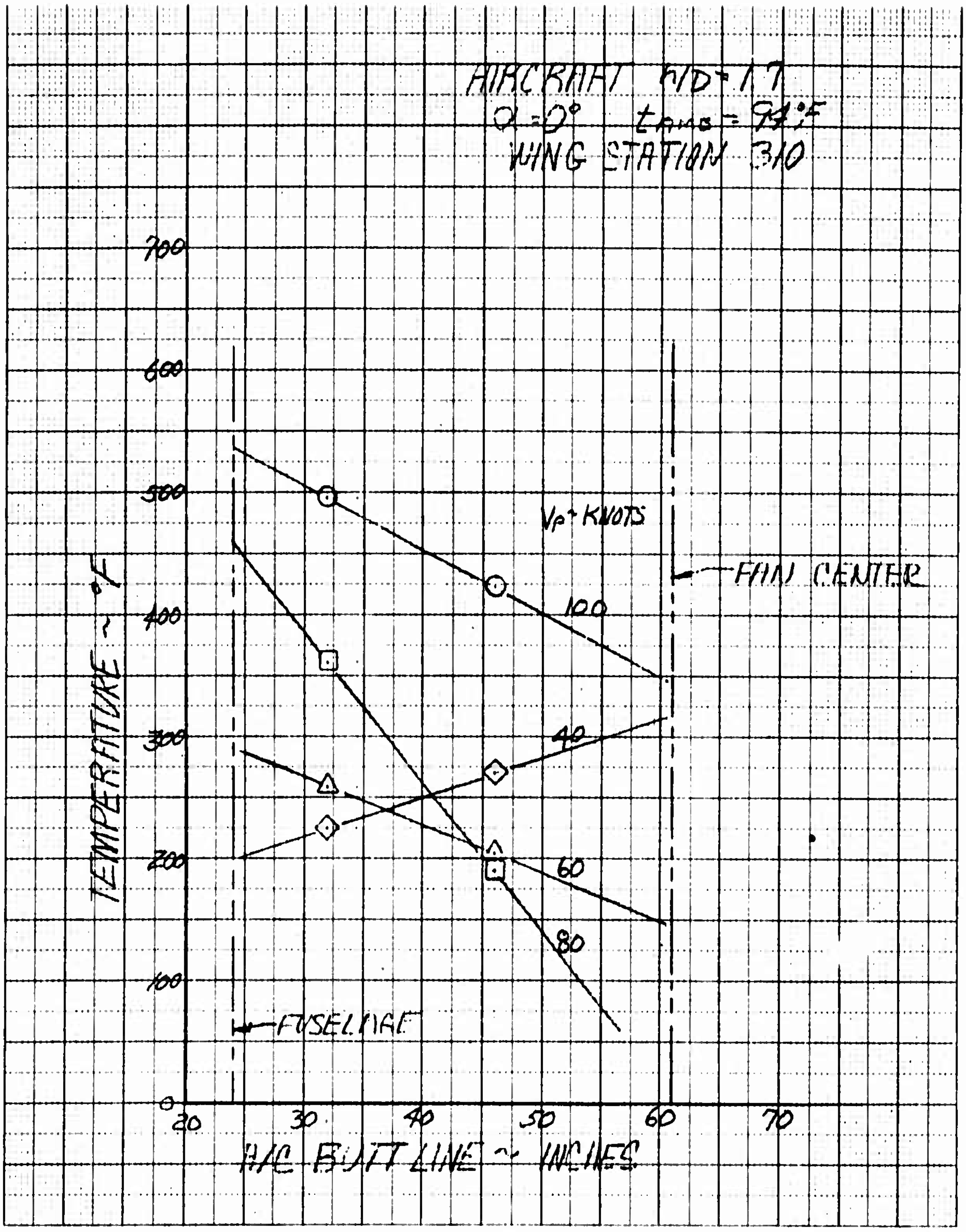

Figure 5.74 Spanwise Distribution of Estimated Trimmed Flight Lower Flap Environment vs Aircraft Velocity: Sta. 310, 100% J85 RPM, h/D = 1.7

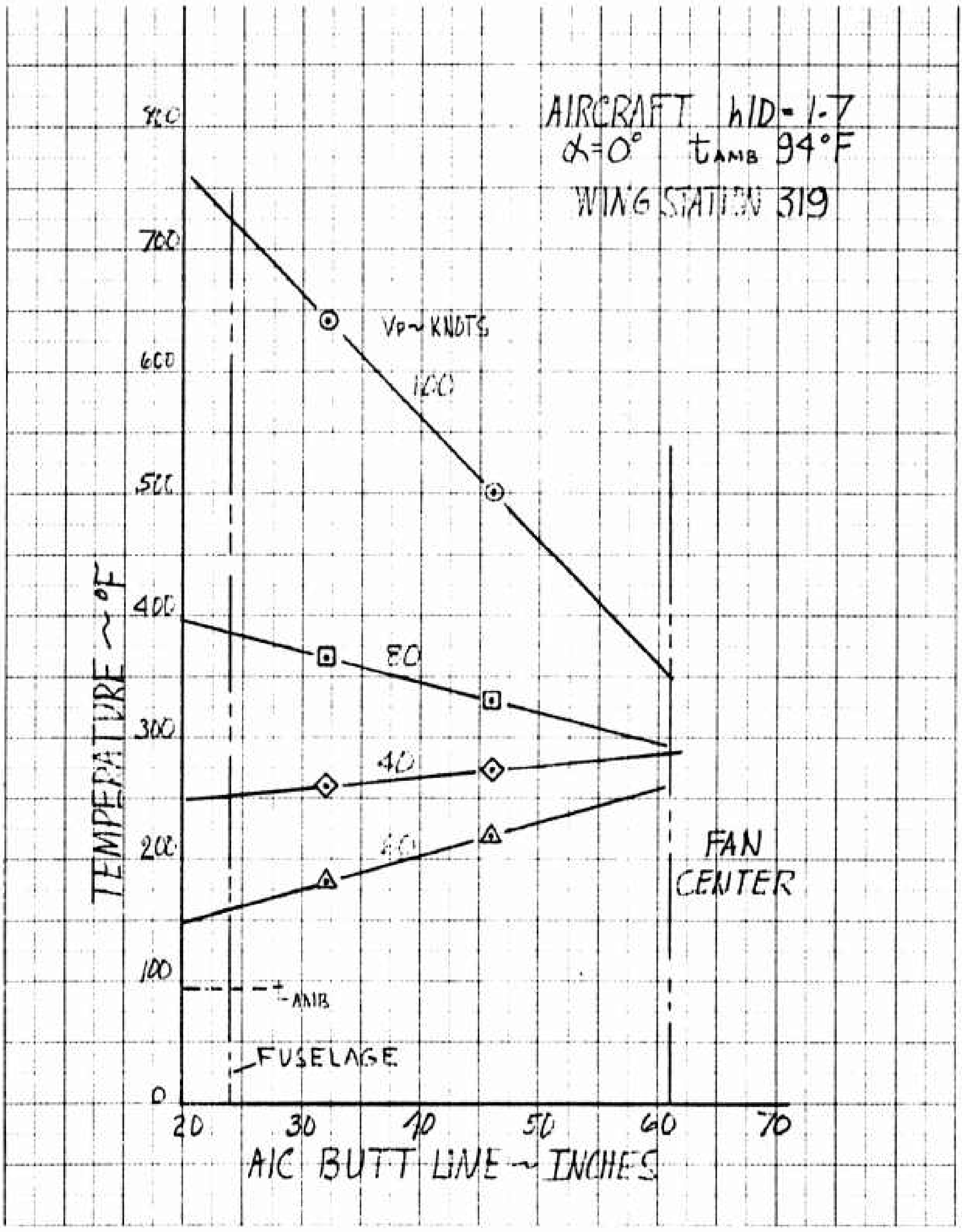

Figure 5.75 Spanwise Distribution of Estimated Trimmed Flight Lower Flap Environment vs Aircraft Velocity: Sta. 319, 100% J85 RPM, h/D = 1.7

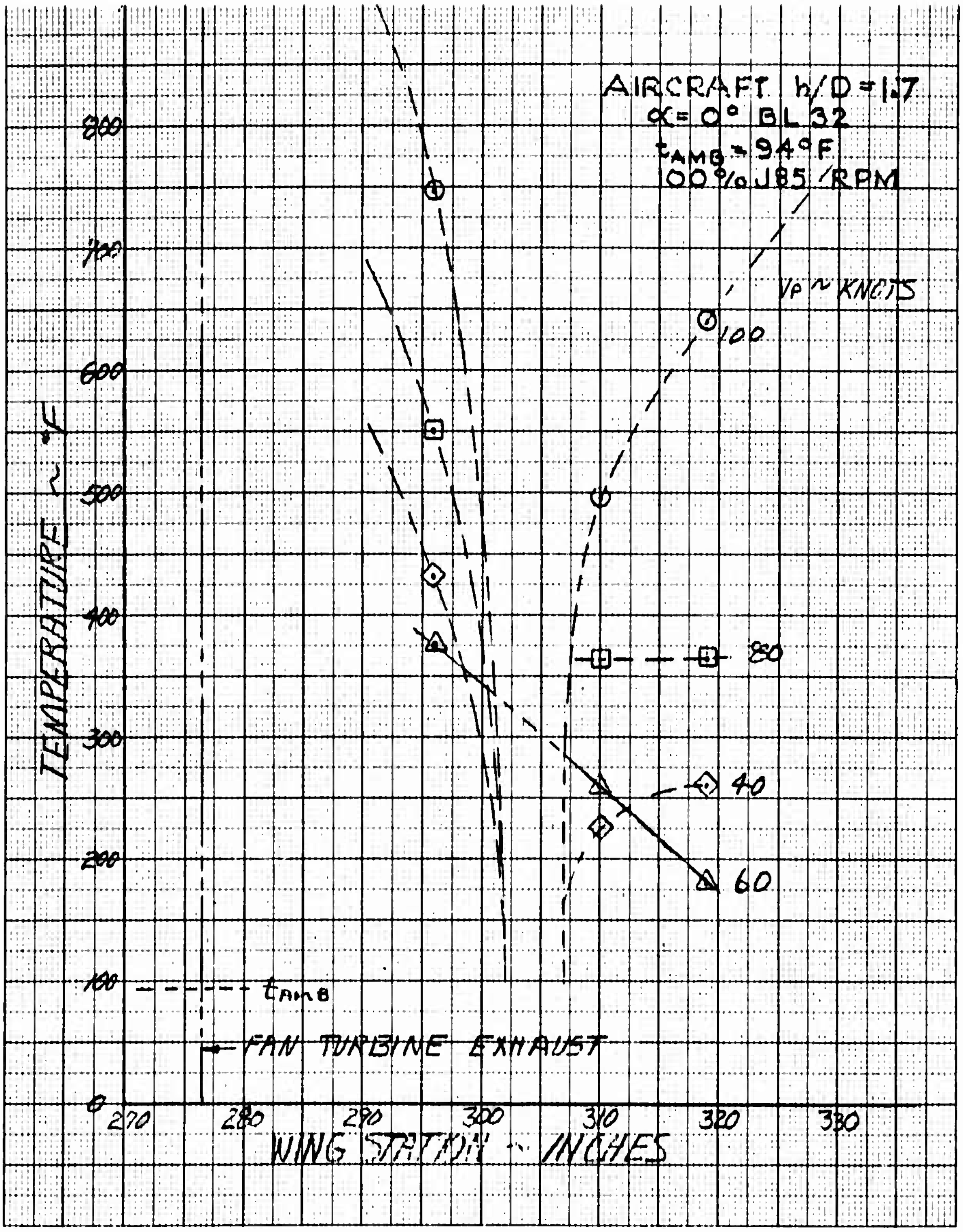

Figure 5.76 Chordwise Distribution of Estimated Trimmed Flight Lower Wing and Flap Environment vs Aircraft Velocity: BL 32, 100% J85 RPM, h/D = 1.7

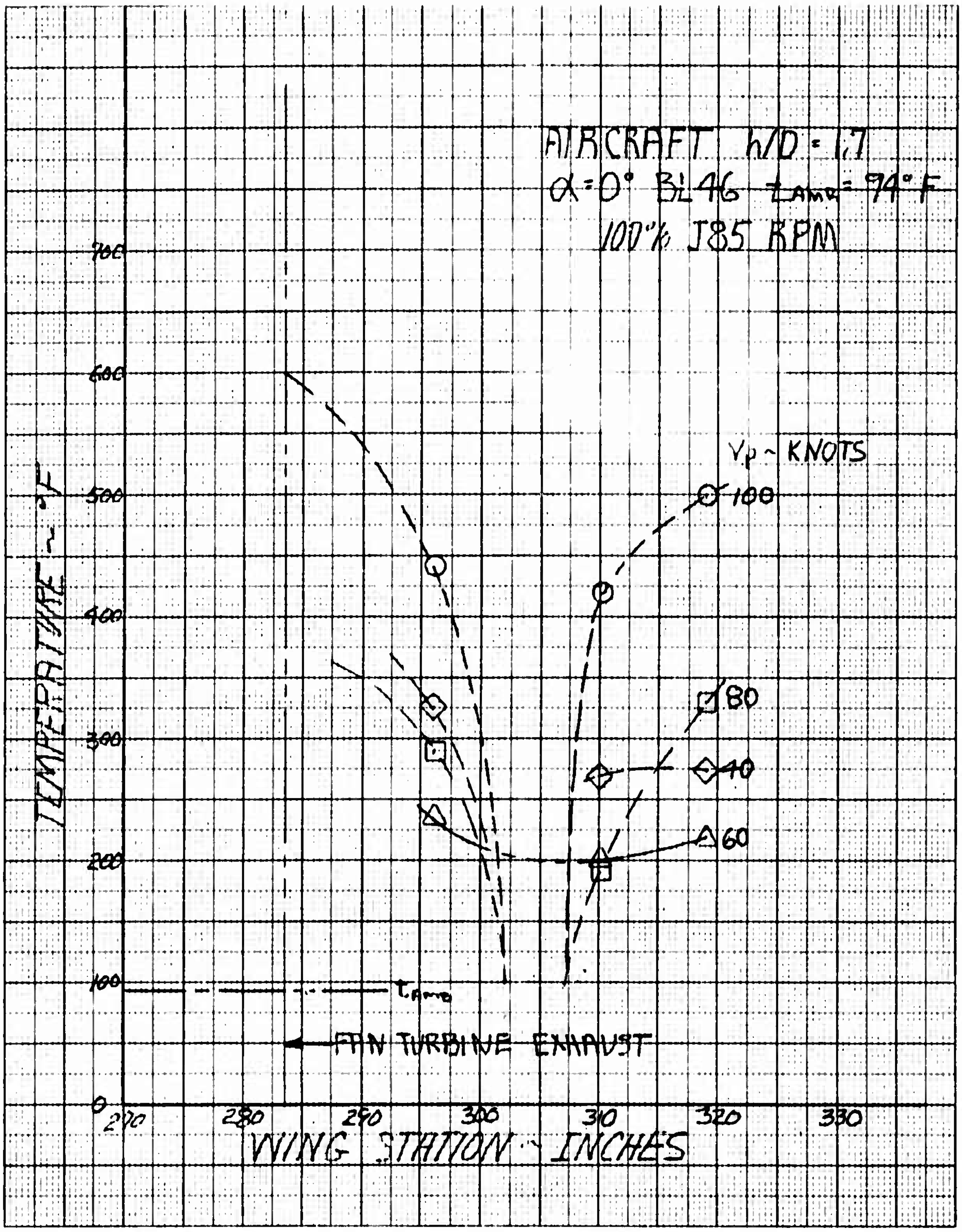

Figure 5.77 Chordwise Distribution of Estimated Trimmed Flight Lower Wing and Flap Environment vs Aircraft Velocity: BL 46, 100% J85 RPM, h/D = 1.7

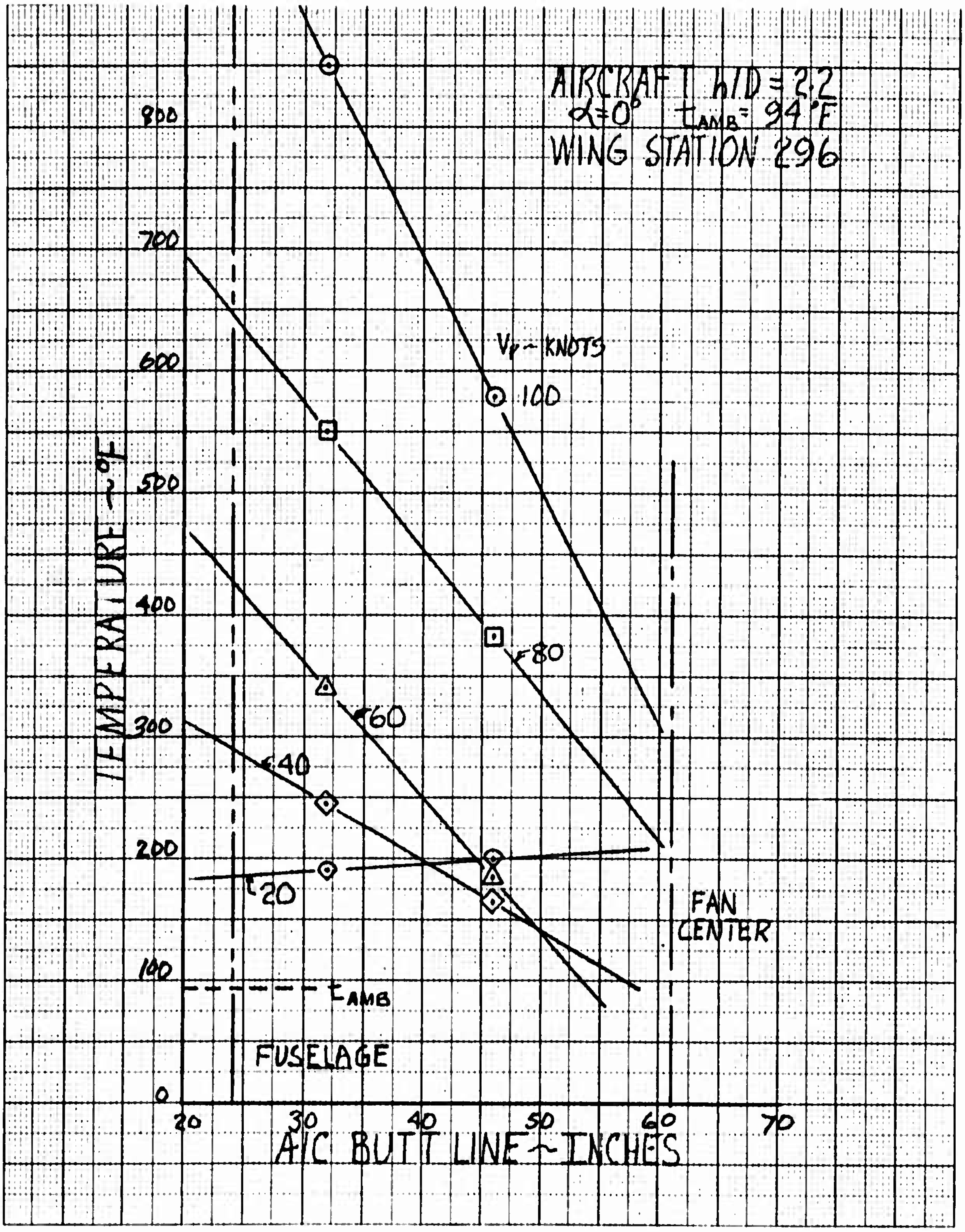

Figure 5.78 Spanwise Distribution of Estimated Trimmed Flight Lower Wing Environment vs Aircraft Velocity: Sta. 296, 100% J85 RPM, h/D = 2.2

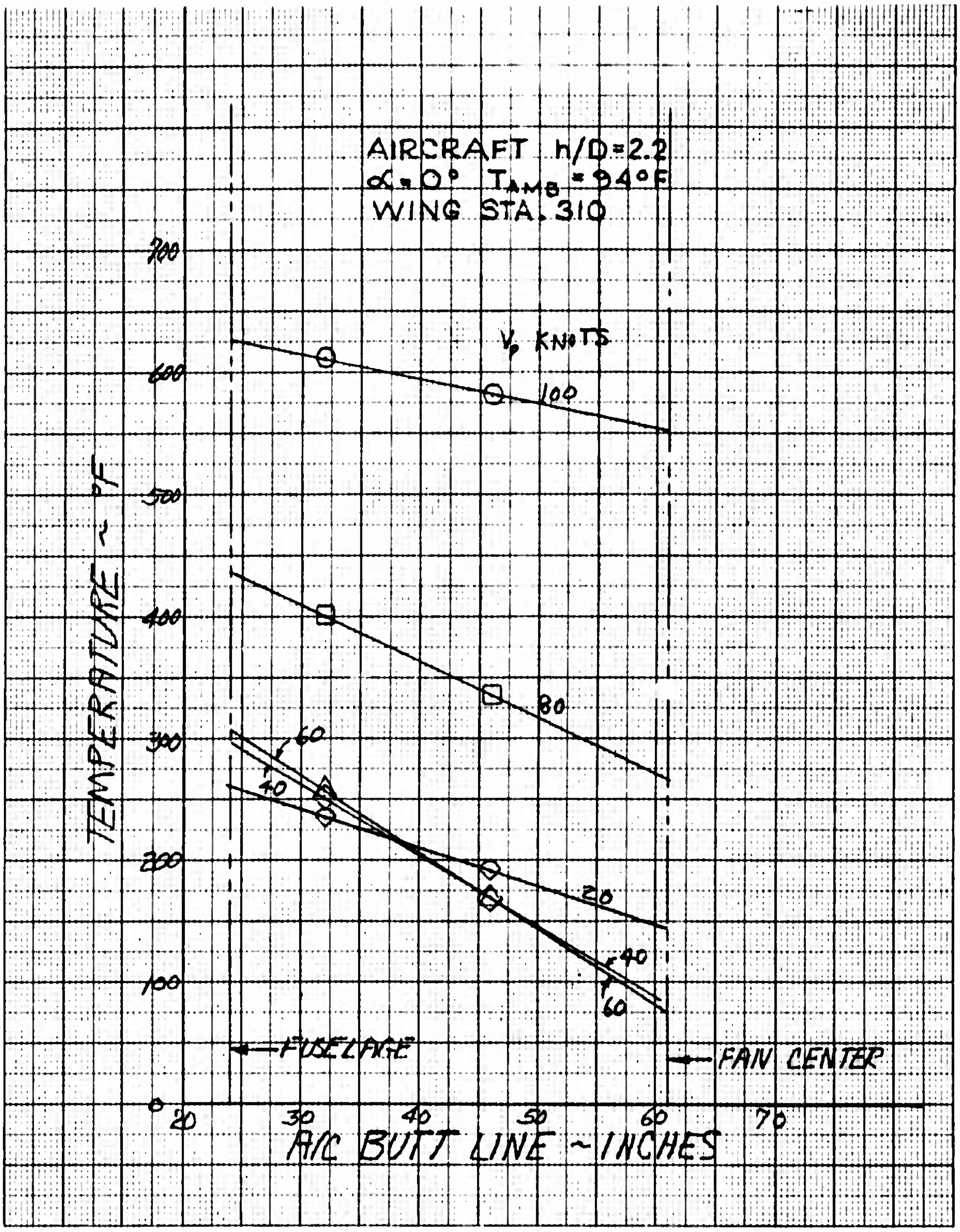

Figure 5.79 Spanwise Distribution of Estimated Trimmed Flight Lower Flap Environment vs Aircraft Velocity: Sta. 310, 100% J85 RPM, h/D = 2.2

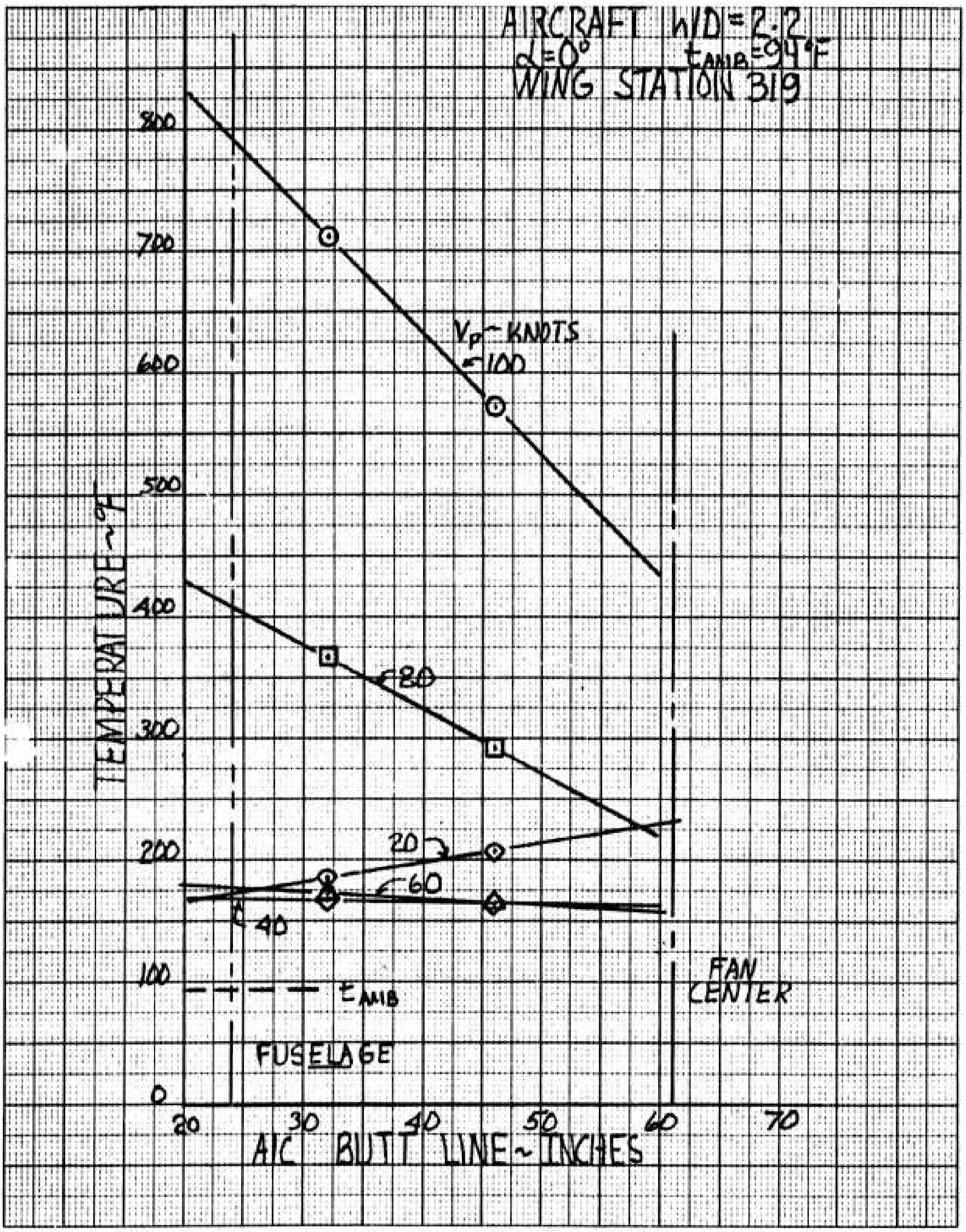

Figure 5.80 Spanwise Distribution of Estimated Trimmed Flight Lower Flap Environment vs Aircraft Velocity: Sta. 319, 100% J85 RPM, h/D = 2.2

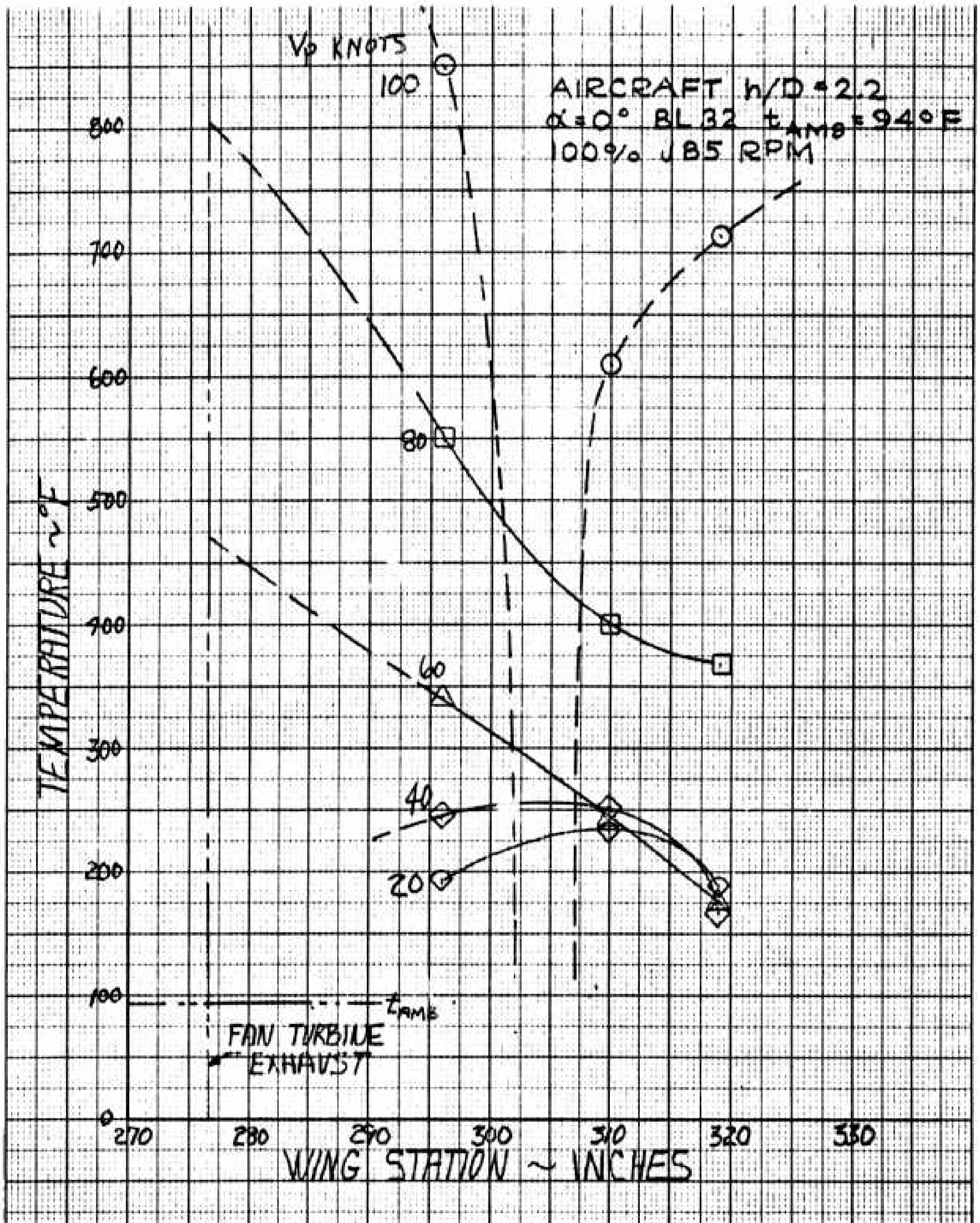

Figure 5.81 Spanwise Distribution of Estimated Trimmed Flight Lower Wing and Flap Environment vs Aircraft Velocity: BL 32, 100% RPM, h/D = 2.2

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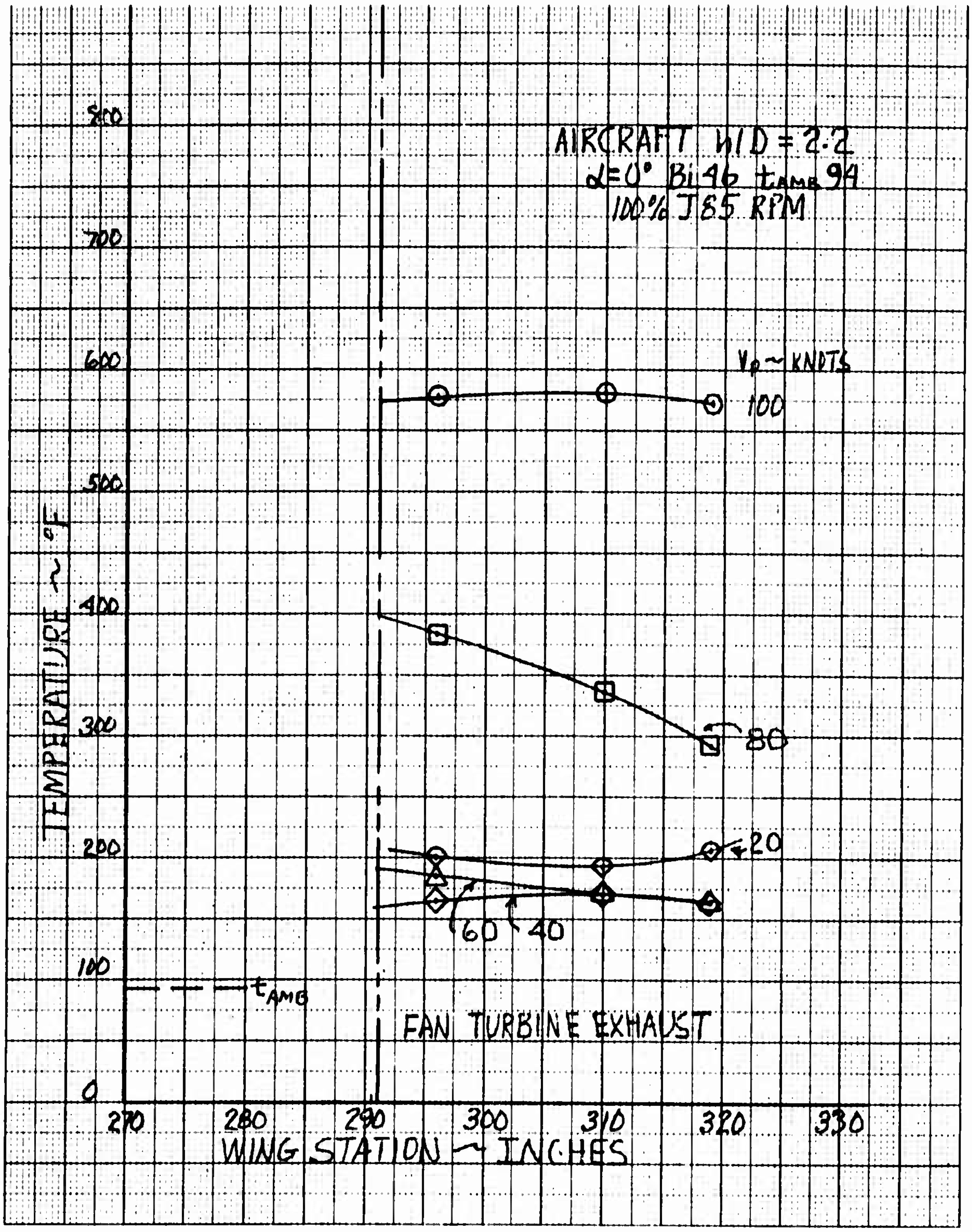

Figure 5.82 Chordwise Distribution of Estimated Trimmed Flight Lower Wing and Flap Environment vs Aircraft Velocity: BL 46, 100% J85 RPM, h/D = 2.2

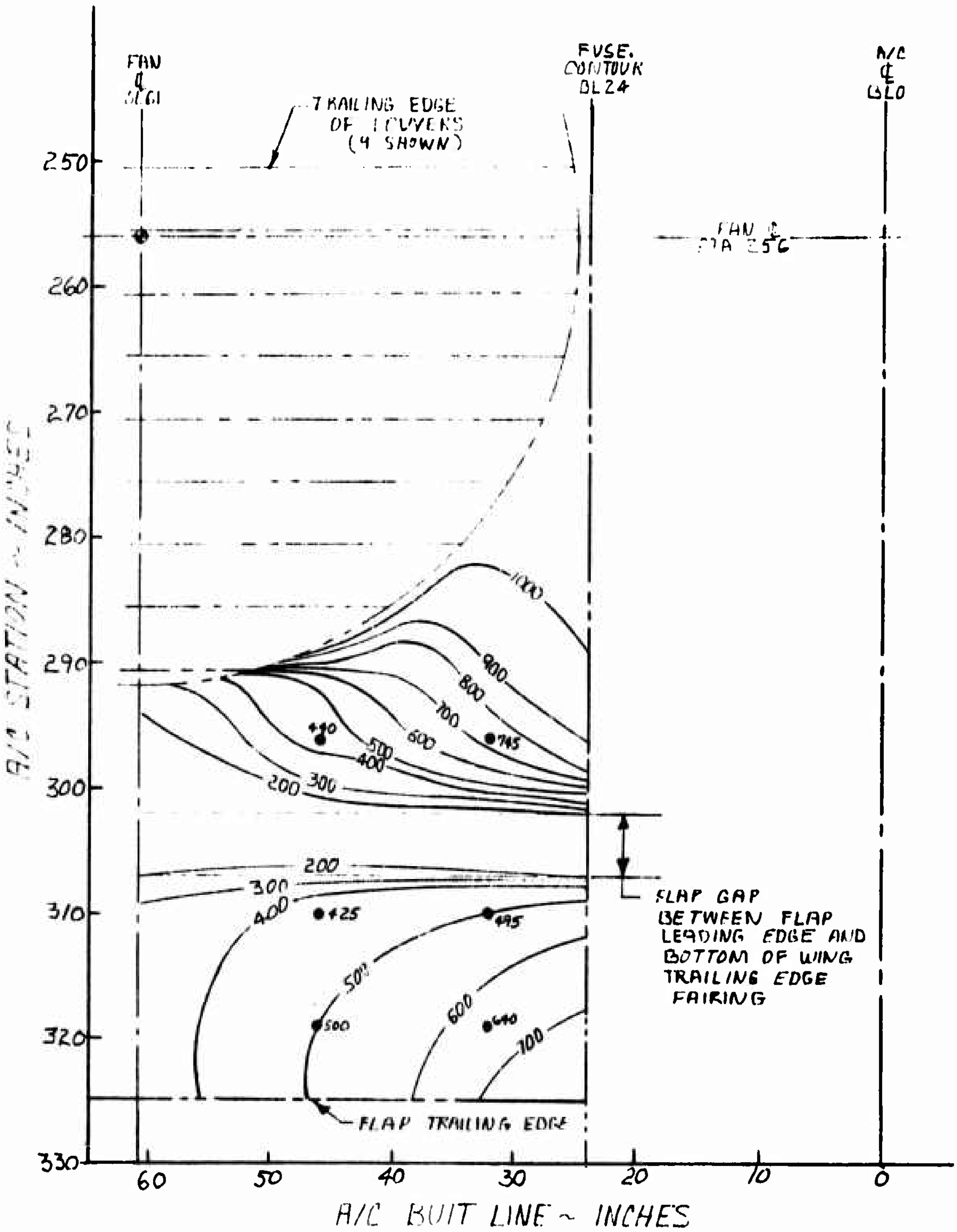

Figure 5.83 Estimated Lower Wing and Flap Environment Isotherms: V_p = 100 Knots, β_v = 47.5°, h/D = 1.7, Sucking Flaps

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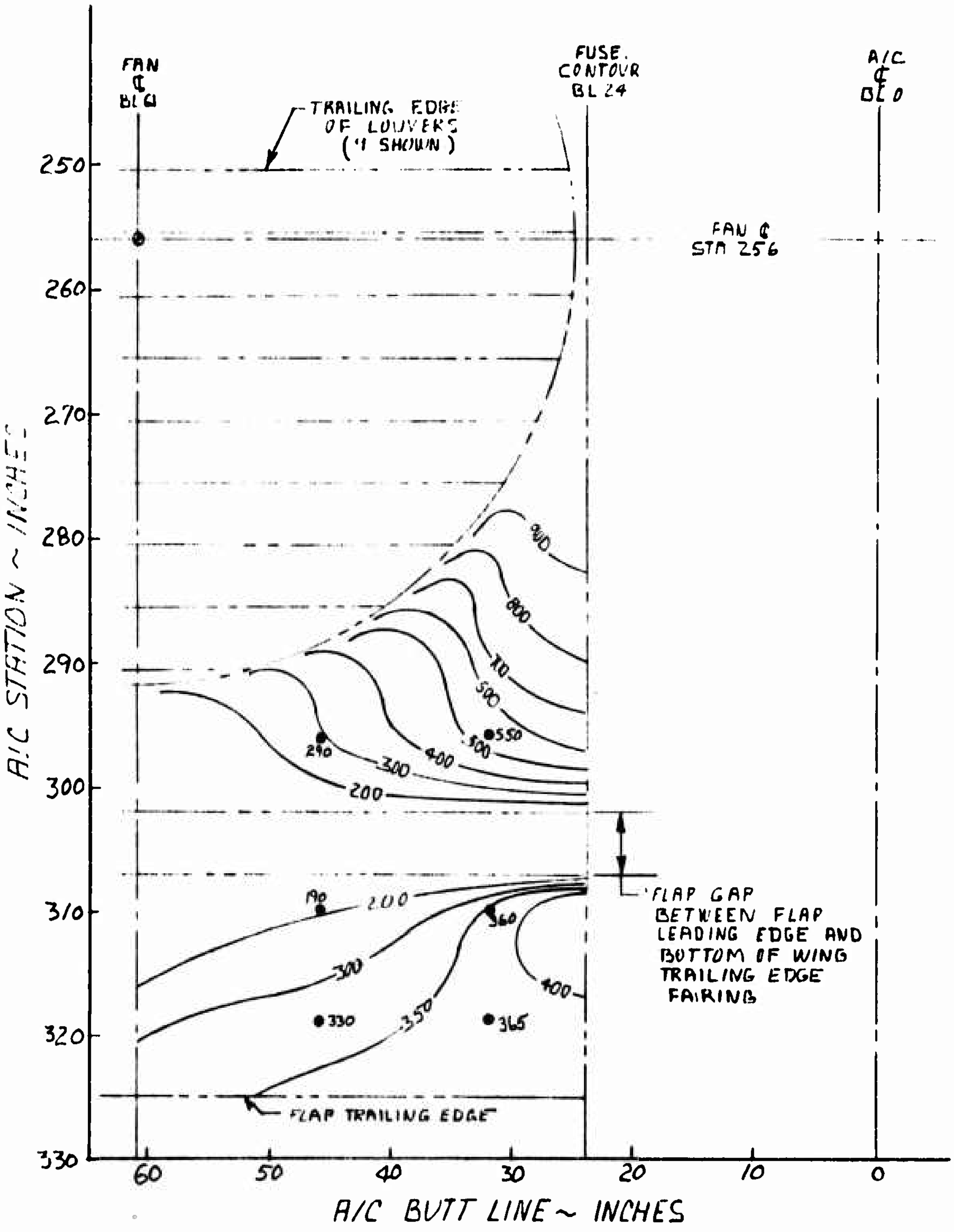

Figure 5.84 Estimated Lower Wing and Flap Environment Isotherms: V_p = 80 Knots, $\beta_v = 37°$, h/D = 1.7, Sucking Flaps

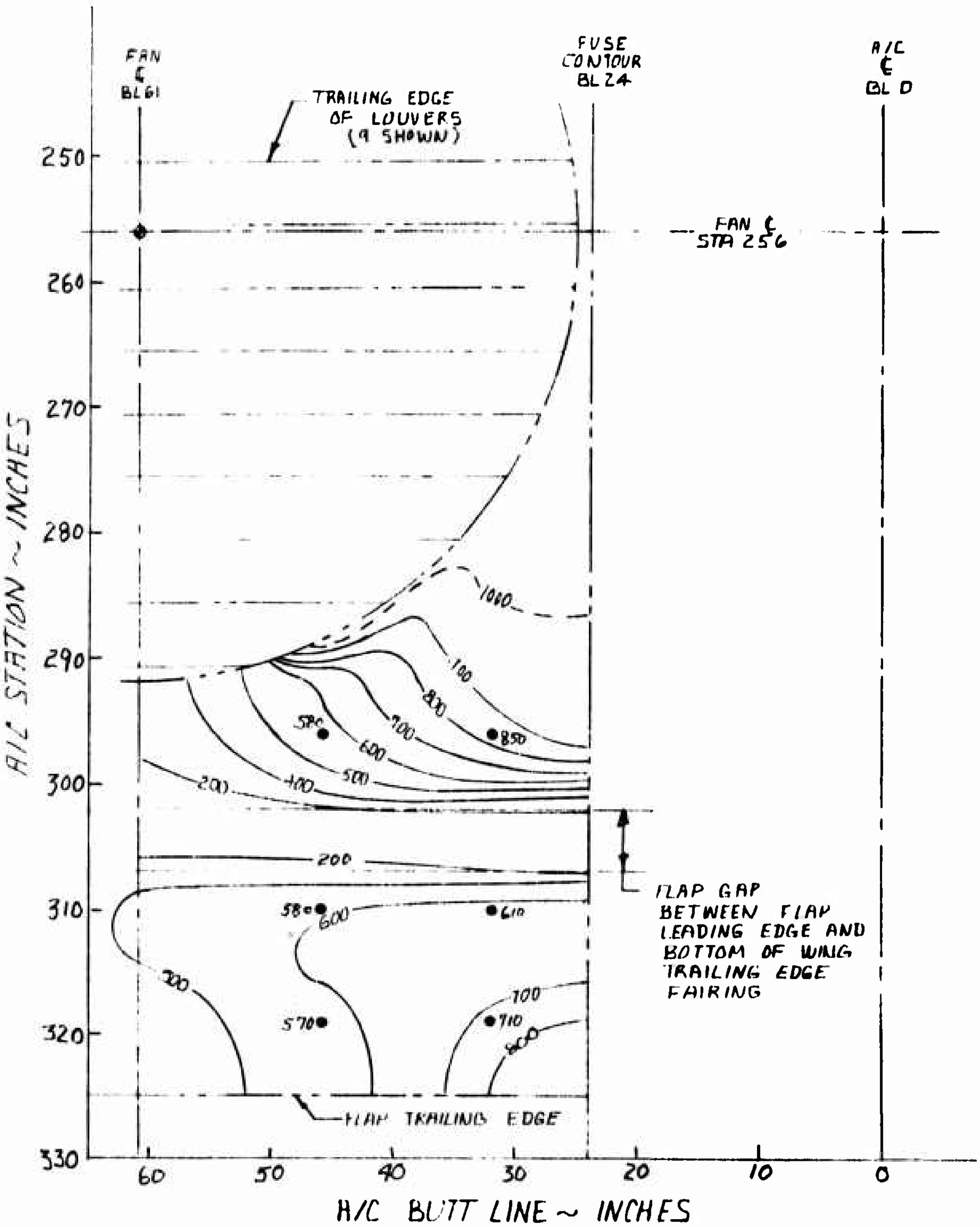

Figure 5.85 Estimated Lower Wing and Flap Environment Isotherms: V_p = 100 Knots, $\beta_v = 47.5°$, h/D = 2.2, Sucking Flaps

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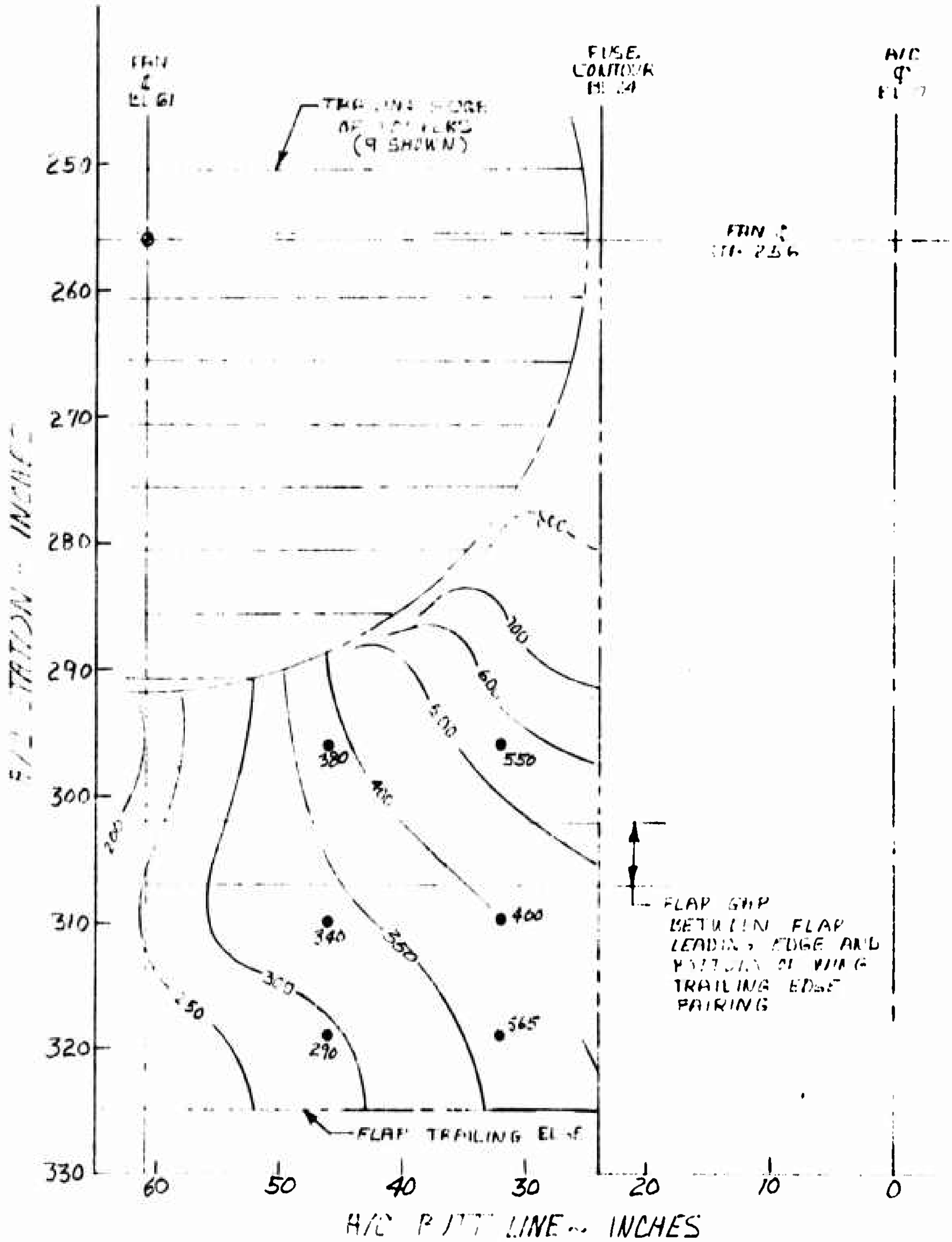

Figure 5.86 Estimated Lower Wing and Flap Environment Isotherms: V_p = 80 Knots, $\beta_v = 37°$, h/D = 2.2, Blowing Flaps

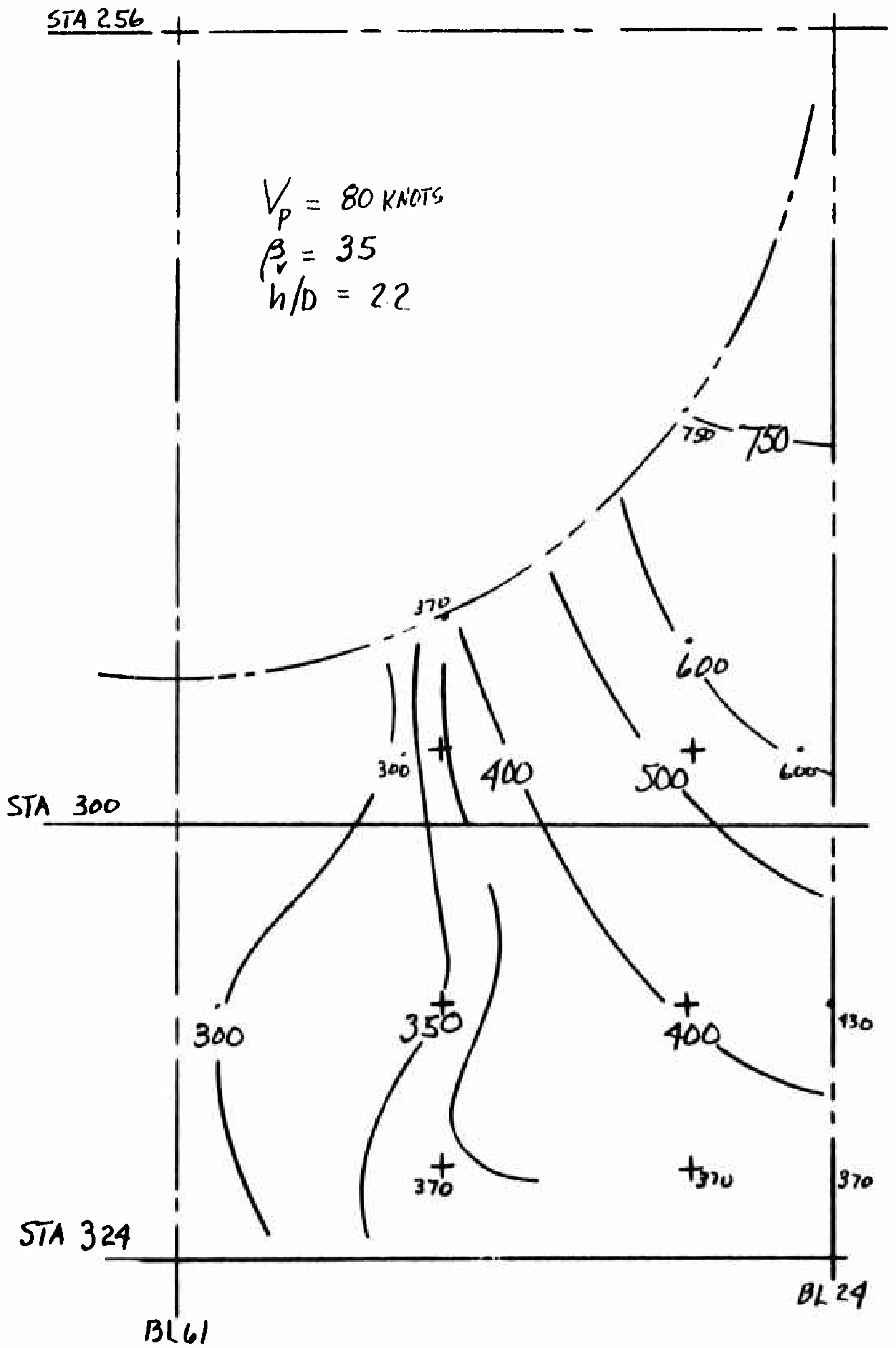

Figure 5.87 Estimated Lower Wing and Flap Environment Isotherms: V_p = 80 Knots, $\beta_v = 35°$, h/D = 2.2, Blowing Flaps

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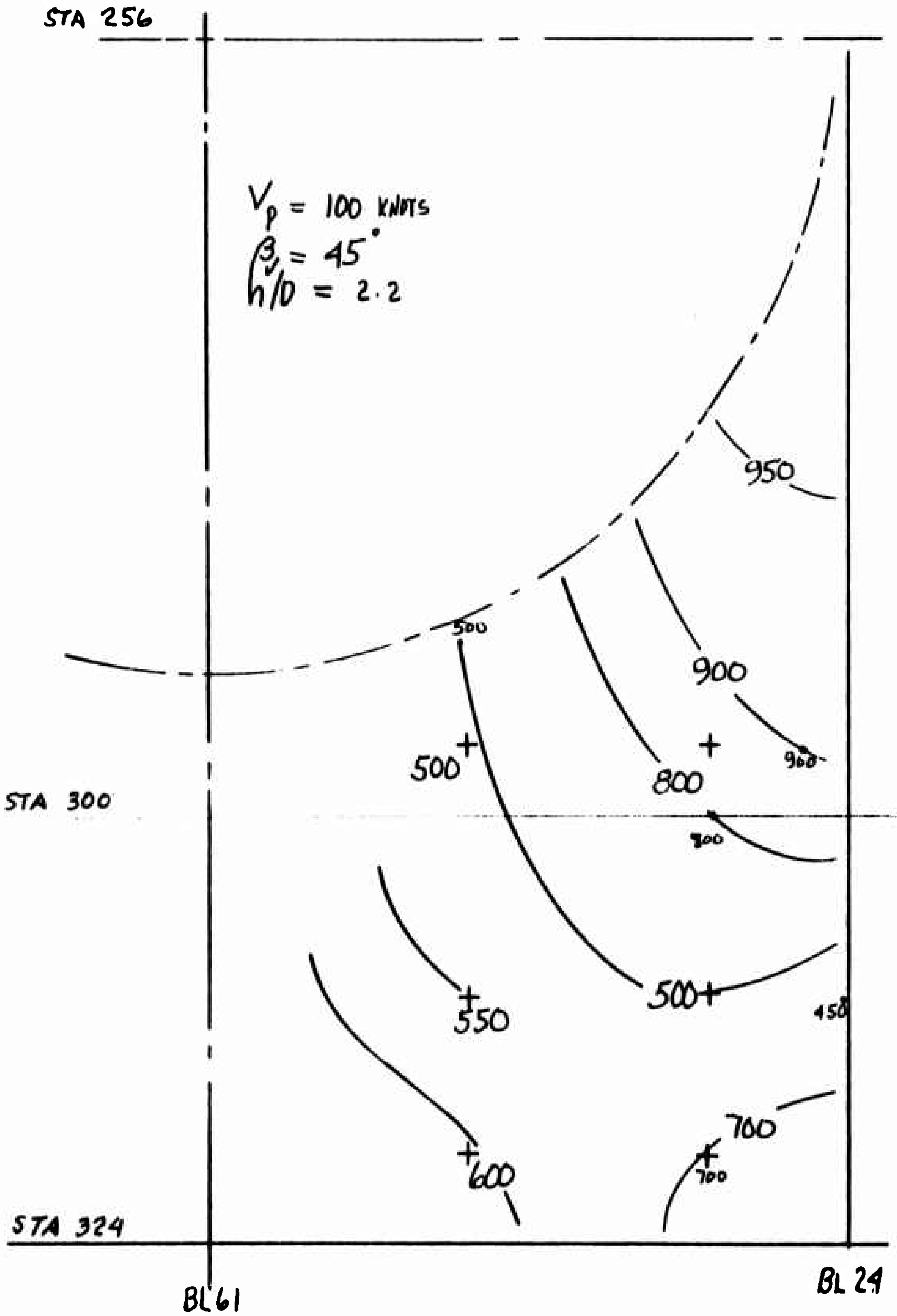

Figure 5.88 Estimated Lower Wing and Flap Environment Isotherms: V_p = 100 Knots, β_v = 45°, h/D = 2.2, Blowing Flap

6.0 STRUCTURAL PROTECTION SYSTEMS

6.1 BACKGROUND

In general, the forward and aft fuselage sections and the wings of the XV-5A aircraft are of conventional construction consisting of aluminum ribs, longerons and frames covered and in direct contact with lightweight metal skins including magnesium, magensium-thorium, aluminum, and titanium alloys, as shown in Figure 2.3. The forward and aft fuselage sections are tied together structurally by a tubular maraging steel spaceframe. As discussed in Section 5.3.5, a number of localized regions of the aircraft surfaces are exposed to relatively severe thermal environments, induced during fan mode and thrust spoiler operation. As suggested in Section 4.1, the seriousness of heating problems arising from such exposures depends upon the nature of aircraft operation, duration of exposure, temperature level of the induced environment and physical properties of the materials involved.

Effective use of the NASA-Ames 40' x 80' wind tunnel requires an aircraft operational capability of at least thirty minutes. Estimated flight test duration requirements of approximate twenty minutes in the fan mode are shown in Table 4-2. It is expected pilot training and familiarization will involve aircraft operation approaching the conditions of Table 4-2. No time requirements were established for the installed systems functional testing (ground tiedown tests) because of the inherently greater flexibility and control of test procedures. "Normal operation" is taken to mean aircraft operation during a typical mission after the pilot is thoroughly familiar with aircraft capabilities and handling qualities.

Material properties require consideration from two viewpoints; (1) strength level vs temperature, and (2) permanent loss of strength due to accumulated soak time. While skin materials selected for the aircraft frequently could withstand the severe thermal environments for the required duration of exposure, the aluminum supporting ribs, frames, and longerons could not withstand the heating without undue loss of strength unless they were protected by some form of insulation or were replaced with higher temperature-strength materials. Overall considerations favored protection by insulation.

Aircraft construction precluded internal insulation of the aluminum ribs, frames and longerons without major changes; therefore, external insulation systems were investigated. Aerodynamic requirements dictated an insulation system with minimum thickness and maximum thermal performance - inherent characteristics of Johns-Manville Min K type insulation.

Protection of the Min K insulation against intense scrubbing action of hot gases was accomplished using epoxy-impregnated fiber glass, elastomeric coatings such as the 3M Company EC1935, or by metal cover. The feasibility of these protection systems has been demonstrated by data in References 10 and 11 for application to aircraft designed for Mach 3.0 to 4.4 capabilities. Installation and production techniques favored general use of fiber glass covers with the edges retained by metal edging. For the small region at the upper-aft, pitch-fan, thrust-reverser door closure, the insulation was enclosed in stainless steel foil.

Thickness requirements were estimated by the procedures of Section 9.5 accounting for the estimated thermal environments of Section 5.0, and the exposure times of Table 4-2. Performance of the selected insulation system was checked for several representative aircraft missions made up of segments from Table 4-2. Cool-down time must be considered in establishing flight conditions if advantage has been taken of the higher allowable temperature limits of Table 4-1 before applying full design loads. The following sections consider local structural protection systems in greater detail.

6.2 UPPER CLOSURE LONGERON, NOSE FAN THRUST REVERSER DOOR

During full nose control fan reverse thrust conditions (full pitch down) experimental data indicated the longeron forming the upper closure of the nose fan thrust reverser door will be exposed to 700° F gases. This condition, while transitory during fan mode flight, may persist for relatively long periods during ground and wind tunnel testing. Preliminary evaluations led to selection of 0.5" thick foil-enclosed, Johns-Manville Min K insulation installed as shown in Figure 6.1. Steady state calculations, without allowance for contact resistance between the foil and longeron, shows the maximum longeron temperature to be 244° F compared to the 250° F allowable limit at design load conditions (see Section 9.5.1). Sealing of the insulation assembly to the airframe structure was recommended to prevent hot gas blow-by.

6.3 AFT FUSELAGE, THRUST SPOILER REGION

During thrust spoiler use, prior to conversion from turbojet to fan mode, spillage and deflection of the turbojet exhaust gases are expected to produce the estimated environment of Figure 5.2 (see Section 5.2). The maximum duration of operation expected in this condition is from 1.5 to 2.0 minutes - with Table 4-2 calling out the latter. The critical member is the aluminum longeron at approximately WL 110. The estimated gas temperature along the longeron is 550° F from Figure 5.2. Based on the calculation method of Section 9.5.2, a series of time-temperature profiles were prepared for the 0.025" titanium skin protected by 1/8" thick Johns-Manville Min K 518 insulation which was exposed to high velocity gases at temperatures from 600° F to 1200° F for a period of 2 minutes. Maximum temperatures so calculated are presented in Figure 6.2. Slight extrapolation shows a maximum titanium temperature of 280° F compared to the design limit of 250° F. Considering contact resistance between the skin and longeron, the high thermal conductivity of the longeron, the silicone fiber glass insulation cover, and the plus tolerance on operational time and insulation thickness, a nominal 1/8" Min K insulation system is judged satisfactory. To prevent excessive heat input by conduction to the longeron from the titanium skin and frames, the insulation is extended approximately 3 inches below the longeron. The area protected by the insulation pad, (see Figure 6.3) generally followed an estimated 250° F isotherm; however, it was not extended beyond Sta. 463 in the belief that cold gas inflow would shorten the 250° F isotherm at the higher aircraft velocities during thrust spoiler operation.

6.4 UNDERWING INSULATION, LOWER FUSELAGE AND WING SURFACES

In fan mode operation, the underwing thermal environment is expected to be quite severe and of rather long duration (see Sections 5.3.5.3 and 5.3.5.5 and Table 4-2). Two general areas are considered; the fuselage at the wing root, and the inboard lower wing surfaces. The aluminum wing spars are of primary concern for the wing insulation; and the aluminum longerons at the wing root are of primary concern for the fuselage insulation.

As stated in Section 5.3.5.5, the conservative assumption of hot gas flow upward through the flap gap and the environmental isotherms of Figures 5.21 and 5.87 were used to establish underwing insulation requirements. The Figure 5.21 environment established the fuselage insulation system

of Figure 6.4 and the aft fairing insulation system for Figure 6.5. The Figure 5.87 environment established the aft lower inboard panel and spar cap insulation system of Figure 6.5. Data from NASA-Ames Test 177 Run 56 at $\beta_V = 0°$; visual observation of scorched paint on the wing leading edge, and the possibility of forward hot gas flow at high angles of attack, led to the insulation of the lower forward inboard wing panels, spar cap and a portion of the lower wing leading edge.

In order to establish the required insulation for these areas, a series of temperature-time profiles for both aluminum and titanium skins protected by varying thicknesses of insulation and exposed to gas temperatures for 400 to 1000° F were prepared using the method of Section 9.5.2. These data and cross plots are presented in Figures 9.119 through 9.128. Based on these estimates, insulation system requirements were determined as shown in Figures 6.4 through 6.6. The insulation system thermal performance was evaluated for representative missions of Table 6-1 based on Table 4-2 segments with the results shown in Figures 6.7 through 6.10. These are based on insulation thickness only, with no allowance taken for the fiberglass cover, contact resistance between aluminum ribs, frames or longerons and the skin, over tolerance on insulation thickness, etc. Advantage is taken of the Table 4-1 upper temperature limit of 325° F for aluminum because during fan mode operations requiring extended duration, material properties are adequate for the low actual loads involved. For missions where maximum conventional flight loads are to be imposed following fan mode flight, the fan mode portion must be limited at the time to reach 250° F because the insulation prevents rapid cooling. As shown by the data of Figures 6.7 through 6.10, the operational criteria of Table 4-2 are met except possibly for Mission 4 in which case wing ribs might overheat. However, to fly 20 minutes at 100% X353-5B RPM, approximately 1500 lbs. of fuel are required in addition to ground checkout and fuel reserves. While such a mission is feasible, it is more likely such a mission would consist of incremental velocities as represented by the case of Figure 6.9. For this condition heating problems would be less severe and the insulation performance would be more than satisfactory.

TABLE 6-1

Insulation Performance Evaluation~ Fan Mode Missions and Operating Conditions

Mission	Segment Table 4-2	Time	h/D	β_v	V_p	X353-5B RPM	X353-5B EGT	Fan Turbine EGT	Thermal Environment	Estimated Skin Temp	
	Case	Min	–		Knots	%	°F	°F	Use Figure	See Figure	Remarks
1	a	5	1.0	45 to -5	0	<86	<950	<875	5.58	6.7	OK
2	a	5	1.0	45 -5	0	<86	<950	<875	5.58		
	b	1.5	1.0	0	0	100	1250	1045	5.56	6.10	OK
3	a	5	1.0	45 -5	0	<86	<950	<875	5.58	6.7	OK
	c	20	>3.0	0	0	100	1250	1045	TEXT (200°F)		
4	a	5	1.0	45 -5	0	<86	<950	<875	5.58	6.9	OK
	d	20	> 3.0	0 35	0–80	100	1250	1045	5.88	6.10	Limited to 13 min if Fig. 6.10 applicable throughout mission
5	a	5	1.0	45 -5	0	<86	<950	<875	5.58		
	d	5	> 3.0	0 35	0–80	100	1250	1045	5.88	6.10	Slightly limited if Fig. 6.10 applicable throughout. Unduely severe however.
	e	5	> 3.0	35 45	80–100	100	1250	1045	5.87		
6	f	20	1.0	0 35	0–60	86	950	875	5.88	6.8	OK

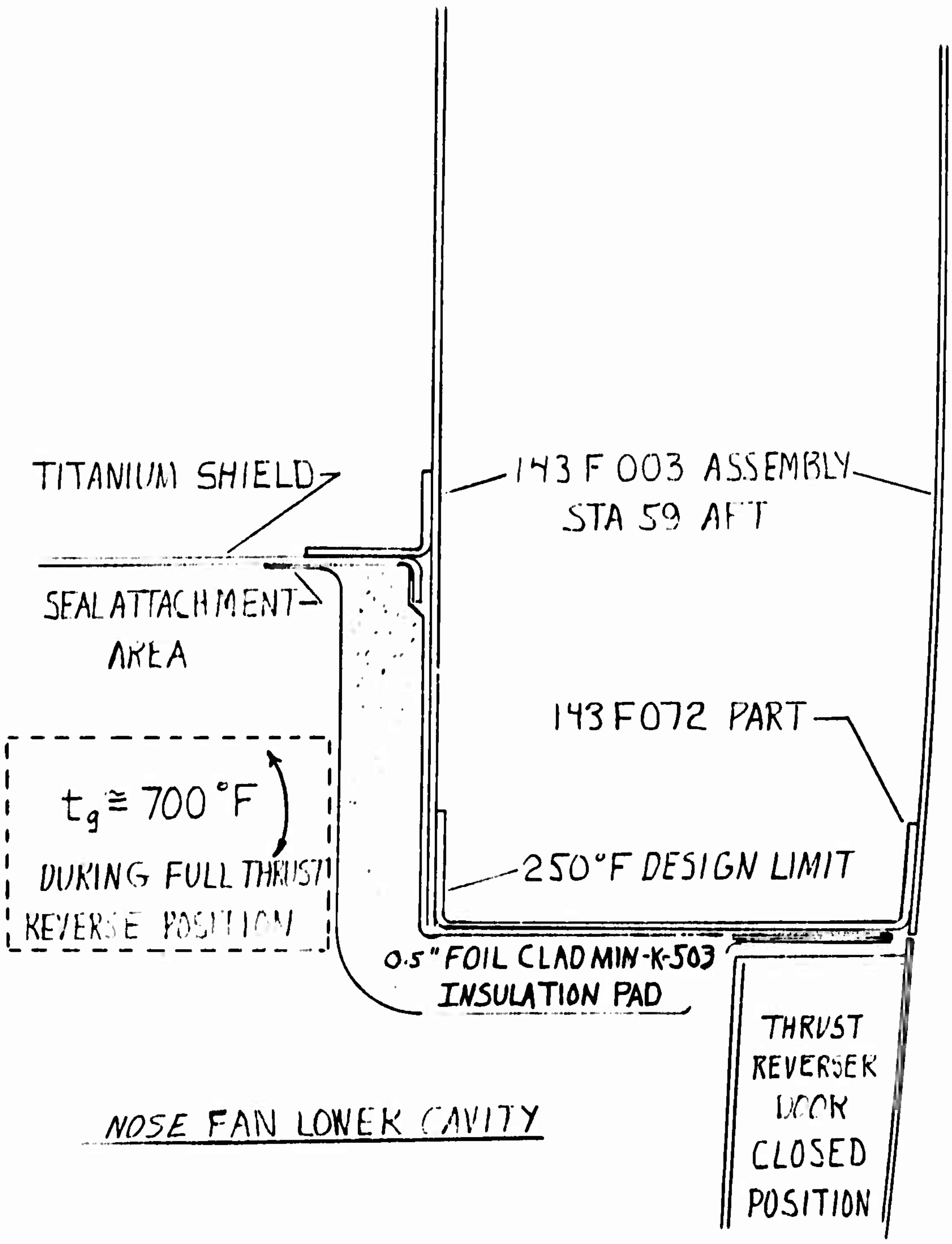

Figure 6.1 Insulation of Part No. 143F003 - Nose Fan Thrust Reverser Door; Upper Closure Longeron

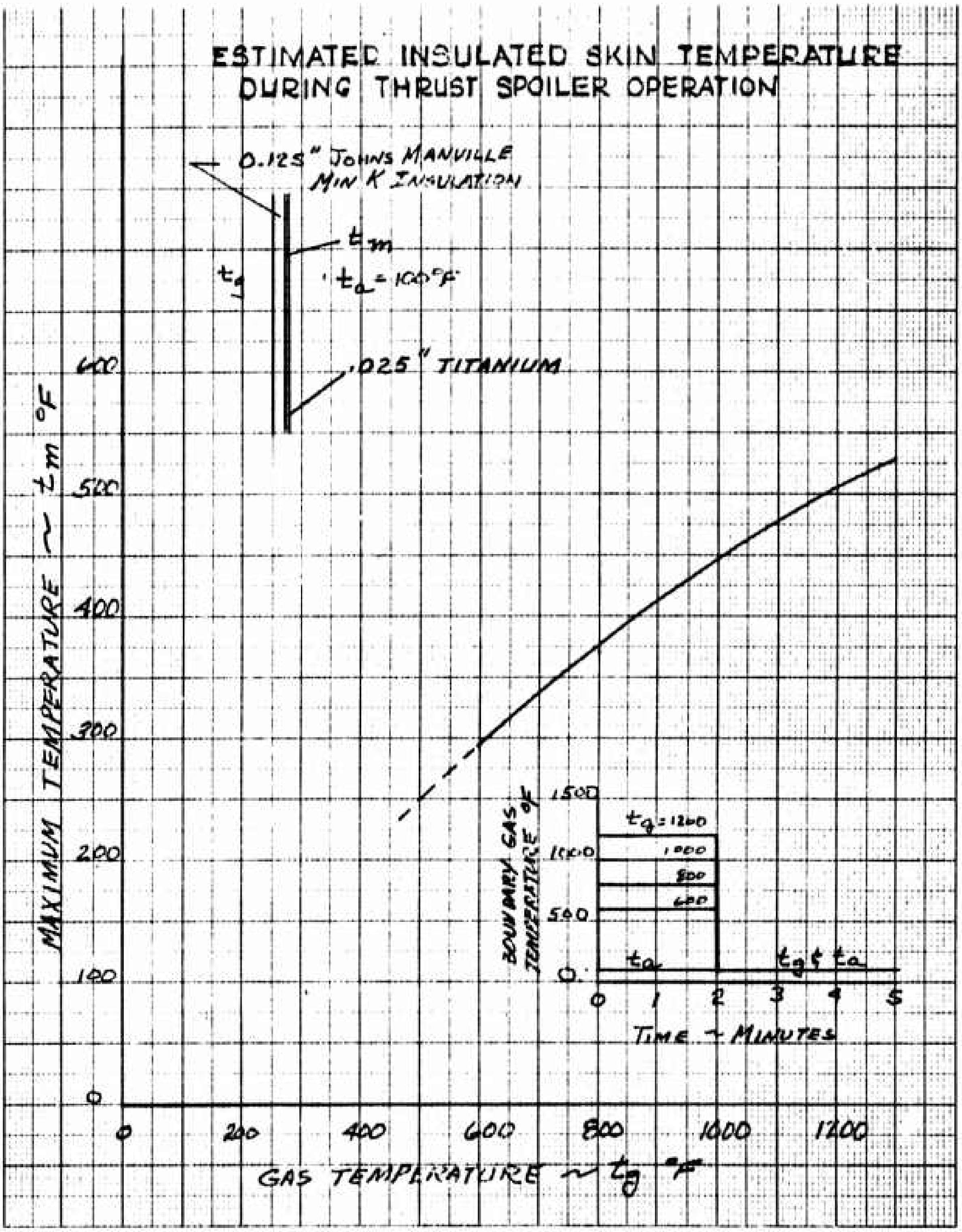

Figure 6.2 Estimated Maximum Aft Fuselage Temperature vs Environmental Temperature

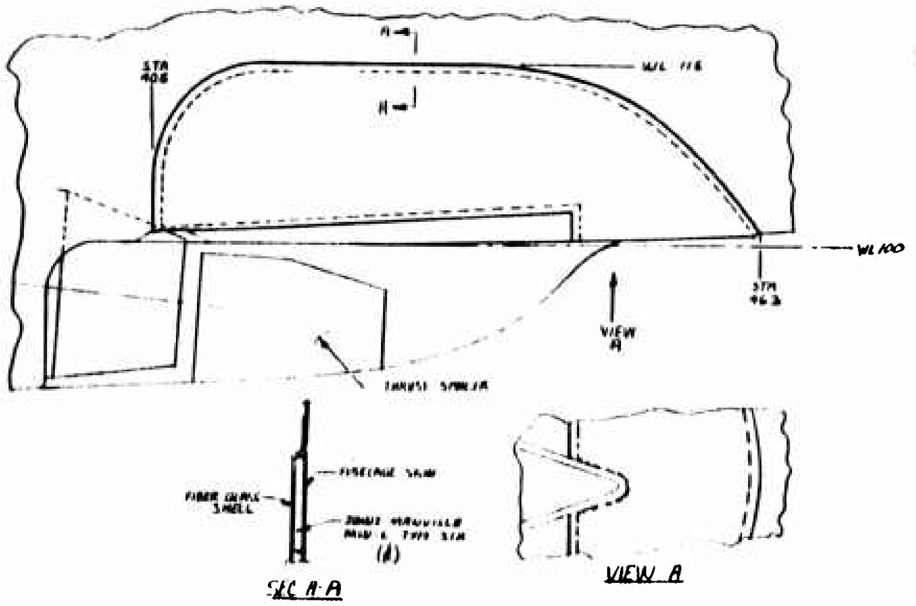

Figure 6.3 Fuselage Insulation System of Aft Fuselage

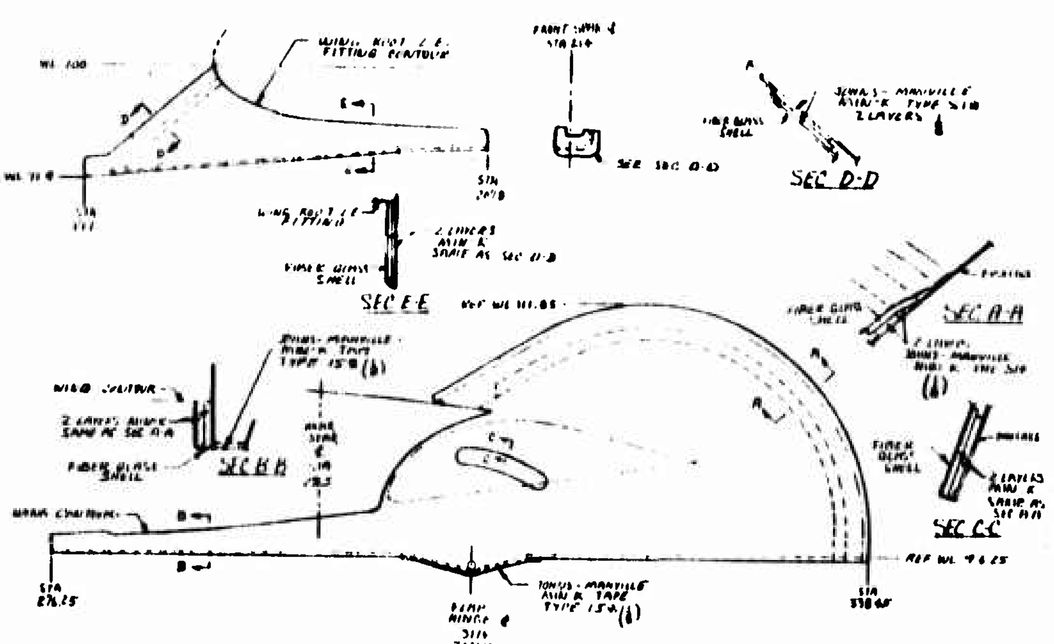

Figure 6.4 Fuselage Insulation System at Wing Root

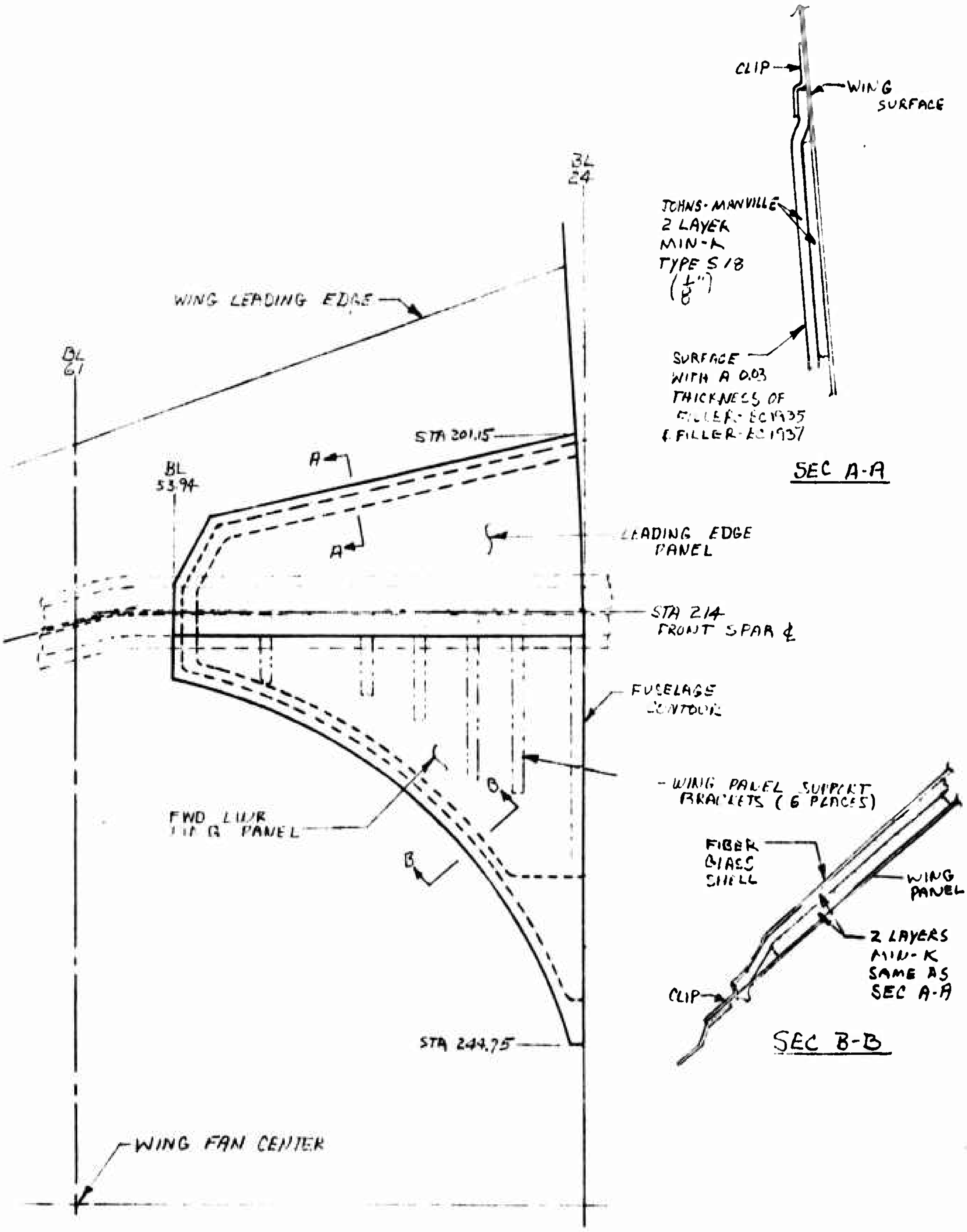

Figure 6.5 Forward Underwing Surface Insulation System

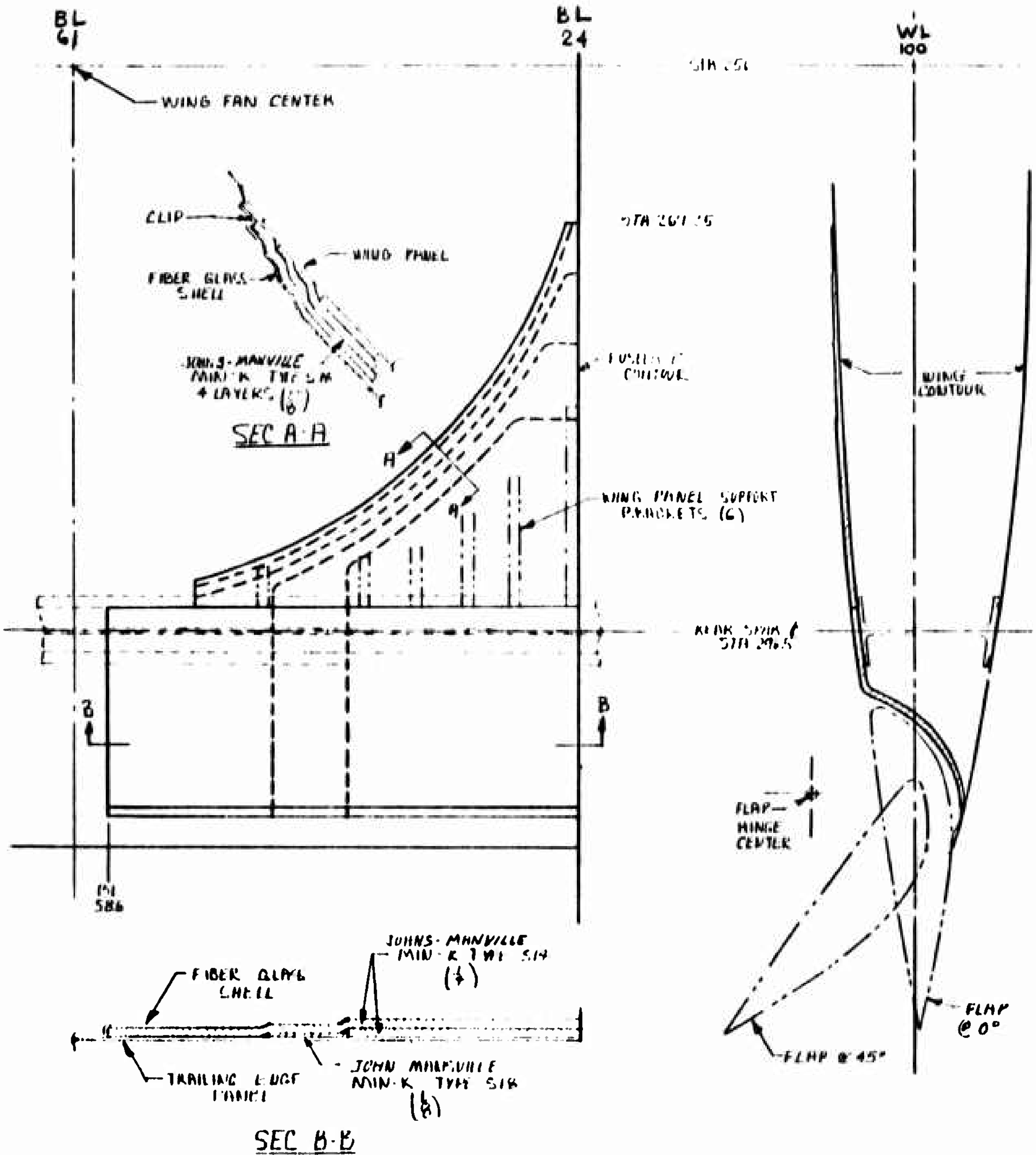

Figure 6.6 Aft Underwing Surface Insulation System

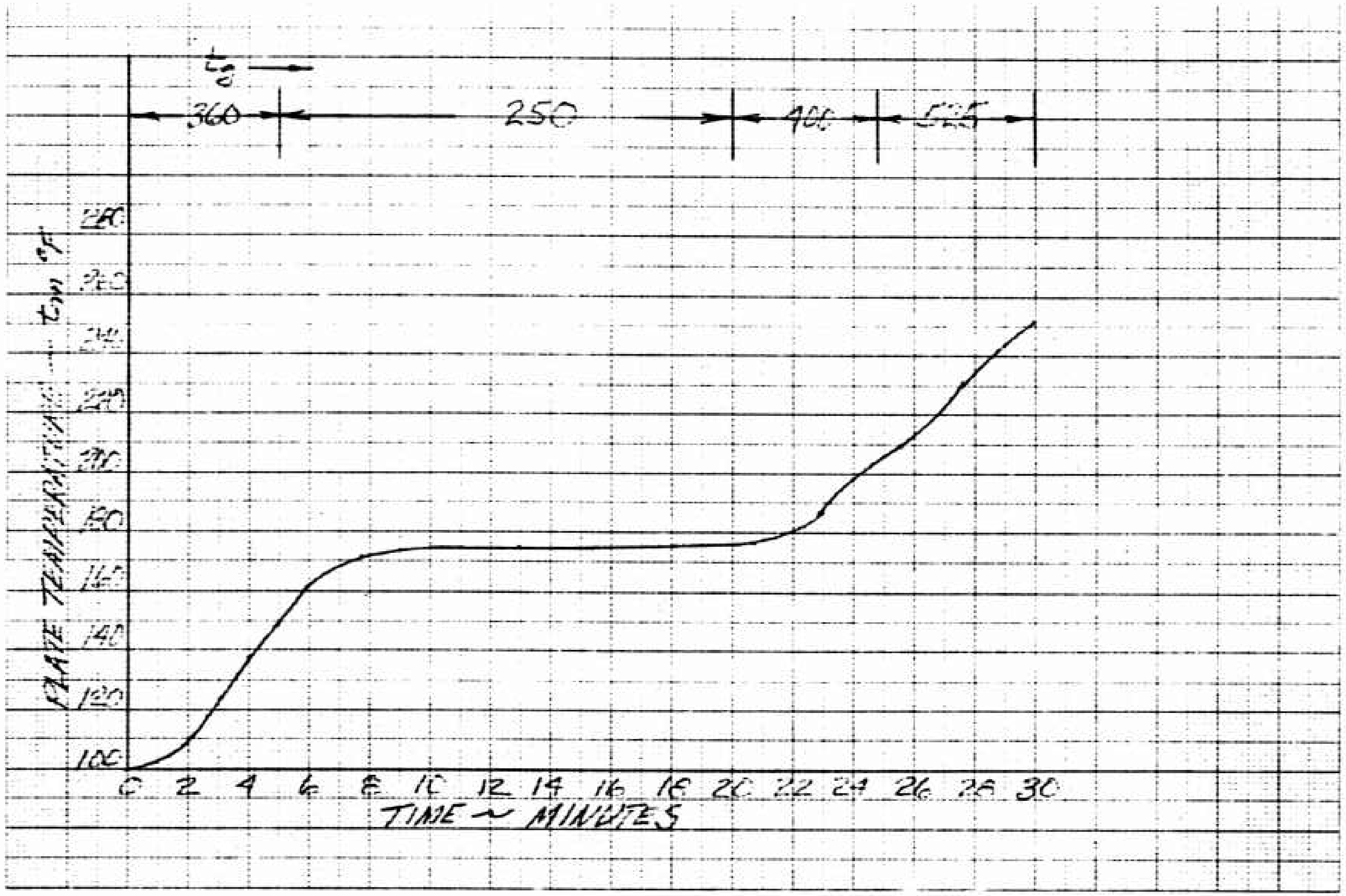

Figure 6.7 Underwing Insulation Performance - Fan Mode Hover and Low Speed Forward Flight

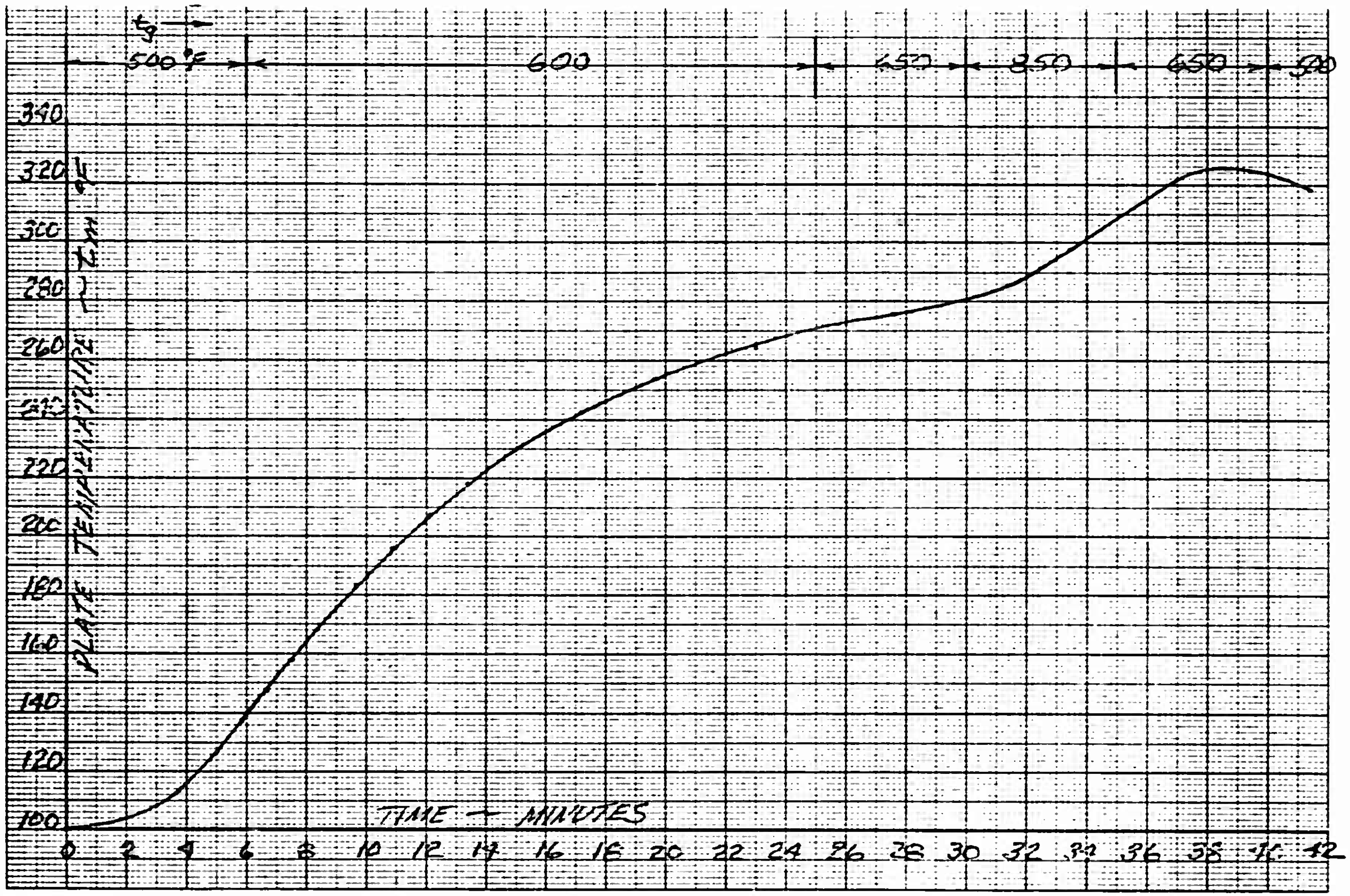

Figure 6.8 Underwing Insulation Performance for Fan Mode Flight to 80 Knots

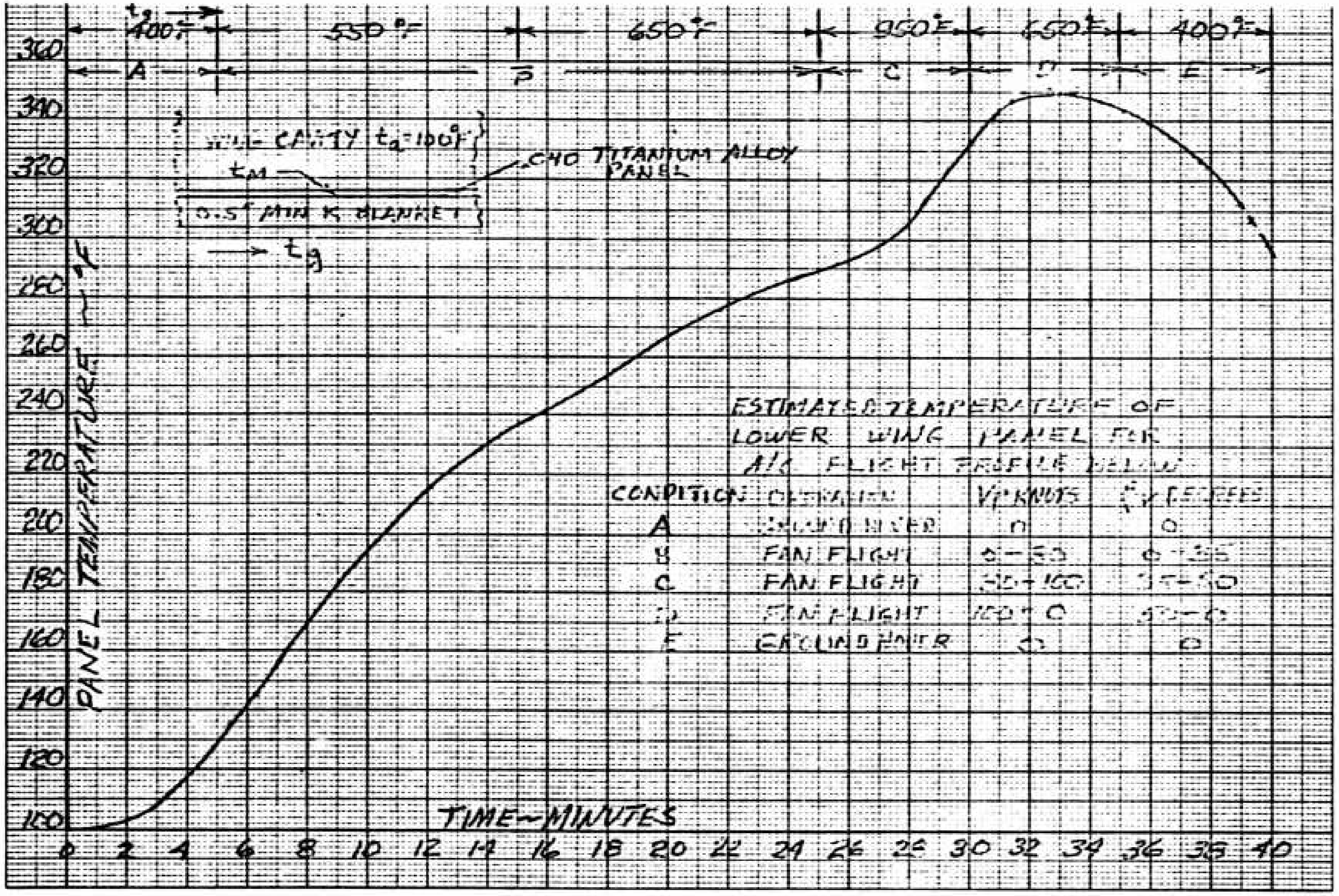

Figure 6.9 **Underwing Insulation Performance for Fan Mode Flight to 100 Knots**

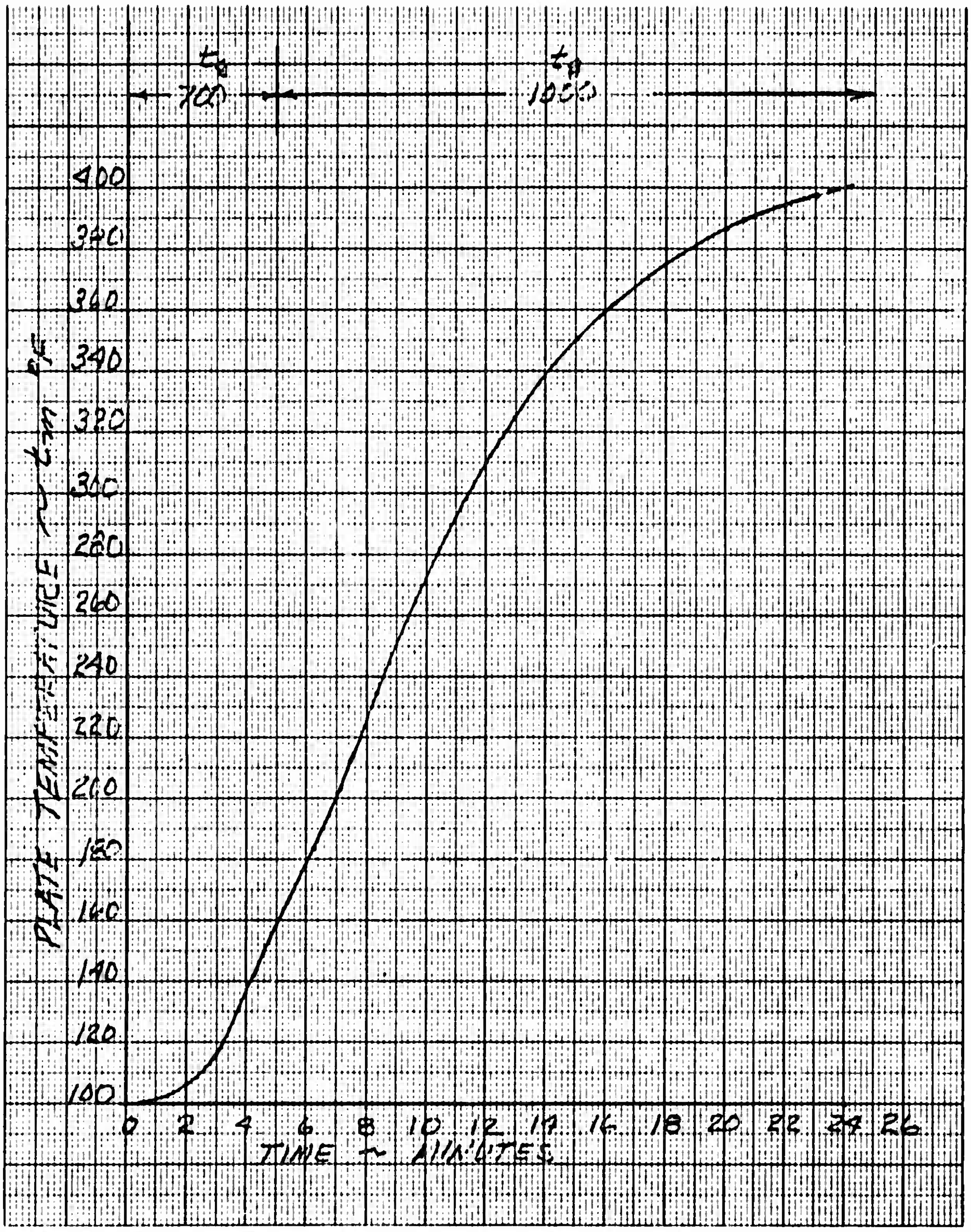

Figure 6.10 Underwing Insulation Performance for Fan Mode Flight at 100 Knots

7.0 COOLING SYSTEM PERFORMANCE

7.1 GENERAL

The two volumes of this report present calculated cooling and structural protection system performance characteristics of the U.S. Army XV-5A Lift Fan Research Aircraft in terms of its estimated and experimentally determined induced environment; in terms of its structural, component, and operational requirements; and in terms of ARDC standard and ANA Bulletin 421 Hot Day conditions.

This section discusses performance of the cooling system as described in Section 3.0 of Volume I. The purpose of this section is to demonstrate that the XV-5A cooling system is adequate to permit orderly conduct of the various aircraft test programs and normal aircraft operation.

Performance is evaluated in terms of cooling air flow rates in the various branches, the cooling air temperatures in these branches, the temperatures of aircraft component or structural members and/or the capability to maintain aircraft components and structural members within safe operating conditions. The latter capability is the most absolute measure of satisfactory system performance, however, the aircraft requirements for extended time of operation are somewhat arbitrary, and the cooling system performance criteria has some degree of flexibility.

Cooling system airflow rates and branch temperatures are presented in Figures 7.1 through 7.98 and in the following sections, together with assessment of system performance capability for ARDC standard and ANA Bulletin 421 Hot Day conditions.

7.2 COOLING FAN PERFORMANCE

Cooling fan performance used in this report is based on the vendor and unpublished test data presented in Tables 7.1 through 7.5 and Figures 7.1 through 7.8. Performance at operating conditions other than those presented is provided by conventional relationships based on fan similarity laws. For further convenience, fan output pressures were expressed in terms of total, rather than static pressure, by adding the fan outlet dynamic pressure calculated, assuming incompressible flow. In

conventional operation, tailpipe ejectors augment pumping of engine bay cooling air. In the lift fan mode, cooling air ejectors on the fans augment pumping of wing and fuselage air.

7.3 COOLING AIR FLOW RATES

The estimated cooling air flow rates presented in Figures 7.9 through 7.76 (and also 7.95) represent balanced values for the aircraft and its various coolant passages in fan and turbojet modes as calculated by procedures of Section 9.3. Fan mode data are presented in Figures 7.9 through 7.19 and 7.95. Turbojet mode data are presented in Figures 7.20 through 7.76. Total cooling air taken onboard is presented in Figures 7.66 through 7.75 for various one and two-engine turbojet operating conditions.

During operation in the lift fan mode, cooling air ejectors activated by the wing and pitch control fans augment the cooling air blowers. In the conventional mode of operation, cooling air blower performance is augmented by the tailpipe ejectors. The possibility of tailpipe ejector trim back, to relieve back pressuring effects during thrust spoiler operations, led to the brief evaluation of trim back effects on flow rate as shown in Figure 7.76.

7.4 COOLING AIR TEMPERATURES

Operating temperatures of the cooling system and its branches were determined and were based on the XV-5A aircraft operating conditions, the balanced flow rates established in the previous section, and by the methods of Section 9.4. Results are presented in Figures 7.77 through 7.98. Ambient temperatures used for Standard and Hot Day are summarized in Figure 7.77.

7.5 PERFORMANCE EVALUATION

In evaluating of the XV-5A cooling system, the amount of hot gas ingestion is unknown. A clue to ingestion temperature effects is obtained by comparing Standard and Hot Day performance. For example, Figure 7.9 shows an 8% reduction in flow rate through the cockpit, and Figures 7.78 and 7.79 show an increase in cockpit temperature of 45° F while ambient temperature is increasing 35° F. If this trend continues, (such as hot gas ingestion temperature increases of 100° F as have been measured during NASA-Ames Test 177), cooling performance could be

impaired for some aircraft operating conditions. With this reservation in mind, the effectiveness and capability of the cooling system is evaluated by the following:

Cockpit

The estimated cockpit air temperatures during conventional turbojet operation are entirely reasonable as shown in Figure 7.79, which shows that the pilot will be uncomfortable during prolonged low level, high speed flight on a hot day, however, temperatures are low enough that his effectiveness should not be impaired. Similar conditions are expected during prolonged lift fan mode ground testing or hovering in ground effect.

Electronic Compartment

The data of Figures 7.83 and 7.84 show the electronics compartment ventilation is generally satisfactory for most areas of aircraft operation except during low level, high speed flight on a hot day. One exception is the radio which, as configured with the external blower, requires ambient air at or below 131° F according to data of Figure 4.1. As pointed out subsequently in Section 9.4 temperature increases of the electronics compartment cooling air are conservatively based on maximum generator and hydraulic oil cooling loads conditions which normally will not exist. If test results verify that radio ambient air temperature levels are being, or will be exceeded in a desired operating range, the problem is easily resolved. Bypassing approximately 3.5 lbs./min. of air from each cooling air fan directly to the radio will satisfy the radio cooling requirements.

Generator Cooling

Based on cooling air flow rates of Figures 7.13, 7.24, and 7.43 through 7.46, and cooling air inlet temperatures of Figures 7.80 through 7.82, sufficient air is supplied to the generator for its cooling requirements.

Hydraulic Oil Cooler

The hydraulic oil coolers are rated at 250 Btu/min. each for hot day and maximum oil temperature conditions. This is adequate, since the normal continuous duty load is only 42 Btu/min, while for hovering it is equal to, or less than 250 Btu/min. The maximum load of approximately 1000

Btu/min. imposed during preconversion sequences, for a period of only 3 to 10 seconds, should cause no problem.

Center Fuselage Section

Based on Figures 7.85 and 7.86, structural members will not be exposed to excessive temperatures in either fan or conventional modes. Figure 7.86 emphasizes the need for care to minimize joint leakage during installation of crossover and nose fan ducting, and demonstrates the benefits of getting out of ground effect to eliminate its associated ingestion and inflow leakage effects. Note that during ground operation in the fan mode, components will be exposed to at least 190° F air on a hot day.

Engine Bay

Figures 7.87 through 7.91 show adequate ventilation of the engine bay and tailpipe shroud for conventional operation. No problem develops in fan mode operation. Calculations in Section 9.4.11 and Figure 7.91 show turbine case temperatures slightly less than the vendor limit of 1150° F.

Fan Cavities

Figures 7.92 and 7.93 show estimated wing fan cavity air temperature as a function of diverter valve leakage distribution, aircraft Mach number, and gas generator per cent RPM. Superimposed are the stabilized flight conditions, wind tunnel test conditions, limits, etc. These data show low speed, high power, conventional mode operation with the wing fan cavity closed will result in temperatures exceeding either design load or permanent loss of strength limits, therefore, provisions should be made to keep the louvers open during turbojet mode operation to allow escape of hot gases. Similar conditions and arguments apply to the nose fan cavity as shown in Figure 7.94.

In the fan mode, data of Figures 7.95 and 7.96 show no serious heating problem. For hot day operation with specification scroll leakage, wing fan cooling air ejector outlet temperatures are close to 250° F for hovering. During transition, the pressure build-up on the aft fan quadrants increases with increasing speed. The net effect of this pressure build-up is decreasing suction pressure, decreasing cooling air flow rate, and increasing cooling air temperature at the aft wing fan ejector.

Conversely, for the forward ejector, there is increasing performance with increasing forward speeds. A cooling air temperature of 200° F was estimated for the nose fan ejector during hovering. It is estimated that the trend with forward speed will be similar to that of the curve on Figure 7.96 for the aft ejector, while maintaining the 45° F differential.

Aft Fuselage

No provisions are made for cooling or ventilating the aft fuselage section beyond the minor amount of cooling which will occur due to differential surface pressures and leakage air flow. No account was taken of this in estimating the temperatures in the area along the tailpipe and as shown in Figures 7.97 and 7.98. These data show no heating problems.

The general overall evaluation of the XV-5A aircraft cooling system is that its performance is adequate to permit orderly conduct of its various test programs and furthermore, should problems develop, they will be relatively minor, and can be resolved with minor modification of the aircraft and/or its operating procedures.

TABLE 7.1
Large Cooling Fan Performance Test

Run No.	Pressures (Inches H_2O) Static (Fan Disch.)	P_1 (Upstream Orifice)	ΔP (Across Orifice)	Temperatures (Deg. F.) Fan Inlet Dry	Fan Inlet Wet	Metering Duct	Gear Box	Torque (Pd's.)	Brake Horse Power	Flow (C.F.M.)
1	33.0	33.0	0	77	67	80	82	4	2.50	0
2	32.0	33.0	1.0	77	67	81	85	6	3.00	570
3	31.5	32.0	2.0	77	67	82	90	7	3.50	900
4	30.5	32.0	5.0	77	67	82	95	10	5.00	1300
5	30.0	31.5	7.0	77	67	83	100	25	10.75	1550
6	28.5	31.5	9.0	77	67	84	105	32	13.50	1750
7	26.0	31.0	11.0	77	67	84	110	40	16.75	1950
8	24.5	29.0	13.0	77	67	85	115	45	18.75	2100
9	22.5	27.5	15.0	77	67	85	120	52	21.50	2250
10	19.5	25.5	17.0	77	67	86	125	60	24.75	2400
11	16.2	23.0	19.0	77	67	87	130	65	26.50	2600
12	13.5	21.0	21.0	77	67	88	131	72	29.25	2700
13	11.0	19.0	23.0	77	67	88	140	78	31.50	2800
14	8.5	17.5	24.0	77	67	88	146	85	34.00	2900

BAROMETRIC PRESSURE = 29.86 INCHES MERCURY. SPEED = 7811 R.P.M.
RELATIVE HUMIDITY = 56 %

TABLE 7.2
Small Cooling Fan Performance Test

Run No.	Pressures (Inches H_2O) Static (Fan Disch.)	P_1 (Upstream Orifice)	ΔP (Across Orifice)	Temperatures (Deg. F.) Fan Inlet Dry	Fan Inlet Wet	Metering Duct	Gear Box	Torque (Pd's.)	Brake Horse Power	Flow (C.F.M.)
1	22.0	22.0	0	76	66	80	82	5	3.00	0
2	18.8	21.6	2.0	76	66	81	82	8.5	4.25	370
3	18.6	20.4	4.0	76	66	82	88	10.5	5.00	520
4	18.3	20.0	6.0	76	66	82	88	12	5.50	630
5	17.8	20.0	8.0	76	66	82	90	14	6.50	780
6	16.5	19.5	10.0	76	66	83	92	16	7.25	830
7	15.3	19.0	12.0	76	66	83	95	18	8.00	900
8	13.8	18.0	14.0	76	66	83	96	20.5	9.00	970
9	12.2	17.2	16.0	76	66	84	99	21	9.25	1050

BAROMETRIC PRESSURE = 29.91 INCHES MERCURY
RELATIVE HUMIDITY = 60 %
SPEED = 7811 R.P.M.

TABLE 7.3
Cooling Fan Performance - Post Vibration Test

Run No.	Small (9) Fan: Press. (In. H_2O) Static Fan Disch.	Small (9) Fan: Press. (In. H_2O) ΔP Across Orifice	Small (9) Fan: Temp (°F) Meter Duct	Small (9) Fan: Flow (C.F.M.)	Large (7) Fan: Press. (In. H_2O) Static Fan Disch.	Large (7) Fan: Press. (In. H_2O) ΔP Across Orifice	Large (7) Fan: Temp (°F) Meter Duct	Large (7) Fan: Flow (C.F.M.)	Complete Ass'y: Temp. (°F) Fan Inlets Dry	Complete Ass'y: Temp. (°F) Fan Inlets Wet	Complete Ass'y: Torque Rd's.	Complete Ass'y: Brake Horse Power
1	21.8	0	79	0	32.3	0	78	0	75	67	12	5.5
2	18.3	5.3	80	600	31.6	1.0	78	580	75	67	22	9.5
3	16.0	10.0	82	830	31.0	3.0	80	1000	75	67	43	18.0
4	14.0	13.0	83	950	30.0	6.0	82	1420	75	67	56.8	23.6
5	12.0	15.5	83	1050	27.0	10.0	83	1850	75	67	72	29.25
6	10.4	17.0	83	1090	24.8	12.2	83	2050	75	67	83	33.3
7	9.5	18.0	84	1130	21.0	15.3	85	2300	75	67	93	37

Barometric Pressure = 29.31 Inches Mercury
Relative Humidity = 66 %.
Gear Box Temp. = 82°F To 132°F Within 8 Minutes.
Speed = 7811 R.P.M.

TABLE 7.4
Cooling Fan Performance - Maximum Brake Horsepower Test

Run No.	Small (9) Fan: Press. (In. H_2O) Static Fan Disch.	Small (9) Fan: Press. (In. H_2O) ΔP Across Orifice	Small (9) Fan: Temp (°F) Meter Duct	Small (9) Fan: Flow (C.F.M.)	Large (7) Fan: Press. (In. H_2O) Static Fan Disch.	Large (7) Fan: Press. (In. H_2O) ΔP Across Orifice	Large (7) Fan: Temp (°F) Meter Duct	Large (7) Fan: Flow (C.F.M.)	Complete Ass'y: Temp. (°F) Fan Inlets Dry	Complete Ass'y: Temp. (°F) Fan Inlets Wet	Complete Ass'y: Torque Rd's.	Complete Ass'y: Brake Horse Power
1	18.2	6.5	82	660	30	7.2	84	1570	76	66	73	15.25
2	17.0	9.3	83	790	26	11.2	85	1950	76	66	73	[illegible]
3	16.0	9.7	83	820	24	13.0	86	2100	76	66	80	[illegible]
4	15.0	[illegible]	[illegible]	[illegible]	22	[illegible]	[illegible]	2250	76	[illegible]	87	[illegible]
5	14.0	13.5	84	950	20	16.0	88	2350	76	66	92	[illegible]

Barometric Pressure = 29.91 Inches Mercury.
Relative Humidity = 60%.
Gear Box Temp. = 90°F To 140°F Within 5 Minutes.
Speed = 7311 RPM

TABLE 7.5
Cooling Fan Performance - Reduced Speed

SMALL 49 FAN				LARGE 47 FAN				GEAR BOX ASSEMBLY					
PRESS. STATIC FAN DISCH.	(IN H_2O) ΔP ACROSS ORIFICE	TEMP. °F METER DUCT	FLOW CFM	PRESS. STATIC FAN DISCH.	(IN H_2O) ΔP ACROSS ORIFICE	TEMP. °F METER DUCT	FLOW CFM	TEMP. (°F) GEAR BOX	TEMP. (°F) INLET WET	TEMP. (°F) INLET DRY	TORQUE READING	BRAKE HORSE POWER	SPEED (RPM)
													50%
5	0	77	0	8	0	78	0	75	74	65	4	2.5	3905
4	2	78	380	6.7	2	78	840	80	74	65	15	6.75	3905
2.6	4	78	535	4.6	4	78	1180	82	74	65	23	10.0	3905
2	5	79	590	2.5	5.5	79	1420	85	74	65	29	12.5	3905
													75%
12.2	0	79	0	18	0	79	0	89	74	65	7	3.5	5858
10.5	2.0	80	370	17.3	2	80	830	90	74	65	22	9.5	5858
10.0	4.0	80	530	16.8	4	80	1160	94	74	65	30	12.75	5858
9.0	6.2	81	650	15.0	6	80	1420	97	74	65	42	17.75	5858
7.5	8.0	80	750	12.7	8	80	1650	100	74	65	50	20.75	5858
6.9	10.0	80	840	9.5	10.4	81	1900	105	74	65	57	23.75	5858
5.2	11.3	80	870	7.4	12.0	81	2050	111	74	65	64	26.25	5858
													85%
15.7	0	80	0	23.5	0	81	0	116	74	65	11	5.25	6640
14.0	2	80	370	22.0	2	81	830	116	74	65	28	11.75	6640
13.4	4	80	520	22.0	4	81	1150	116	74	65	34	14.50	6640
12.7	6	81	640	21.0	6	81	1420	118	74	65	43	18.00	6640
11.5	8	81	740	19.0	8	81	1650	120	74	65	53	22.00	6640
10.0	10	81	830	16.5	10	82	1850	123	74	65	62	25.50	6640
8.5	12	81	910	14.3	12	82	2050	126	74	65	70	28.50	6640
7.8	13	82	960	11.8	14	83	2200	130	74	65	76	30.75	6640

BAR = 29.91" Hg

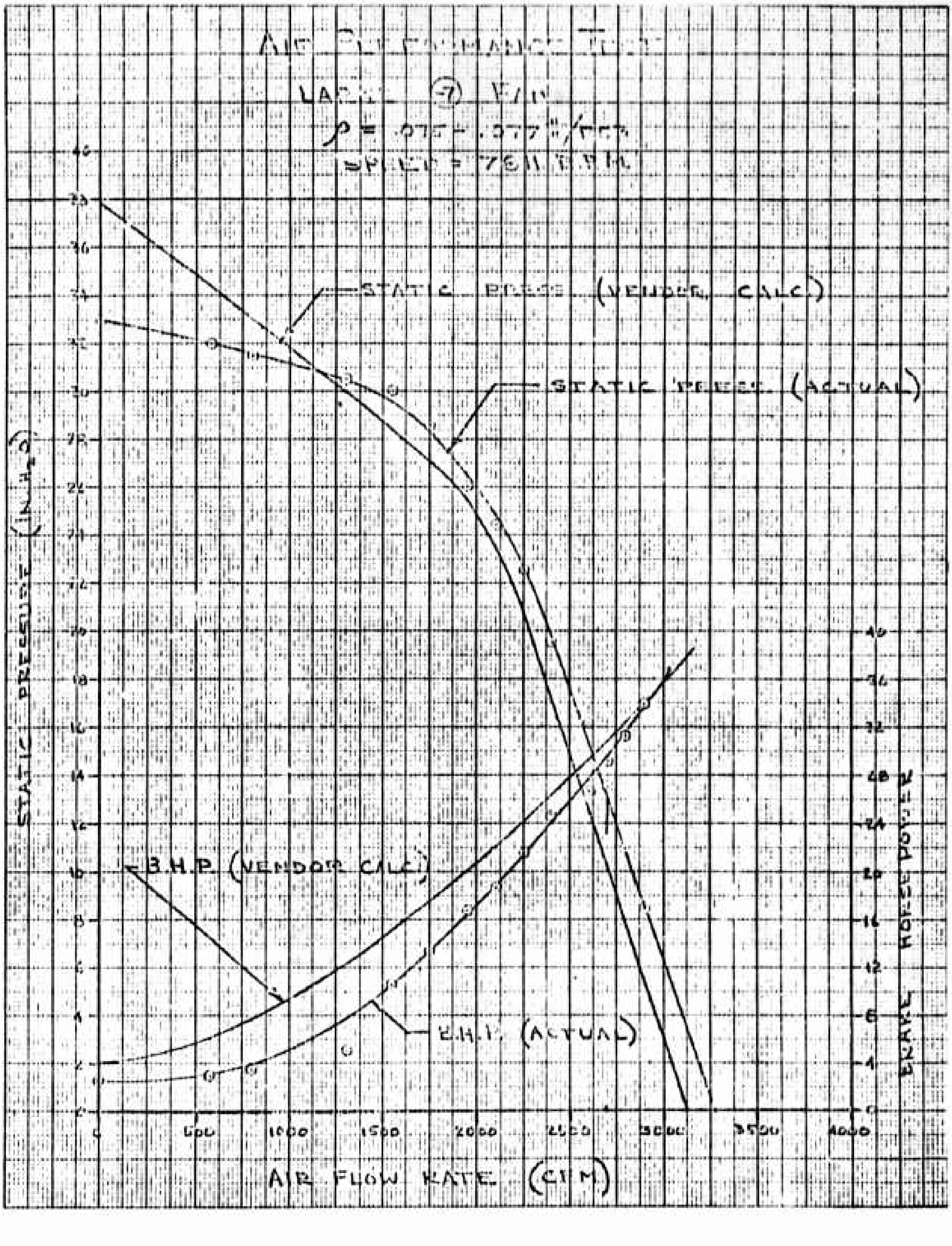

Figure 7. 1 Large Cooling Fan Performance - ρ = . 075- . 077 lbs/ft^3, 7811 RPM

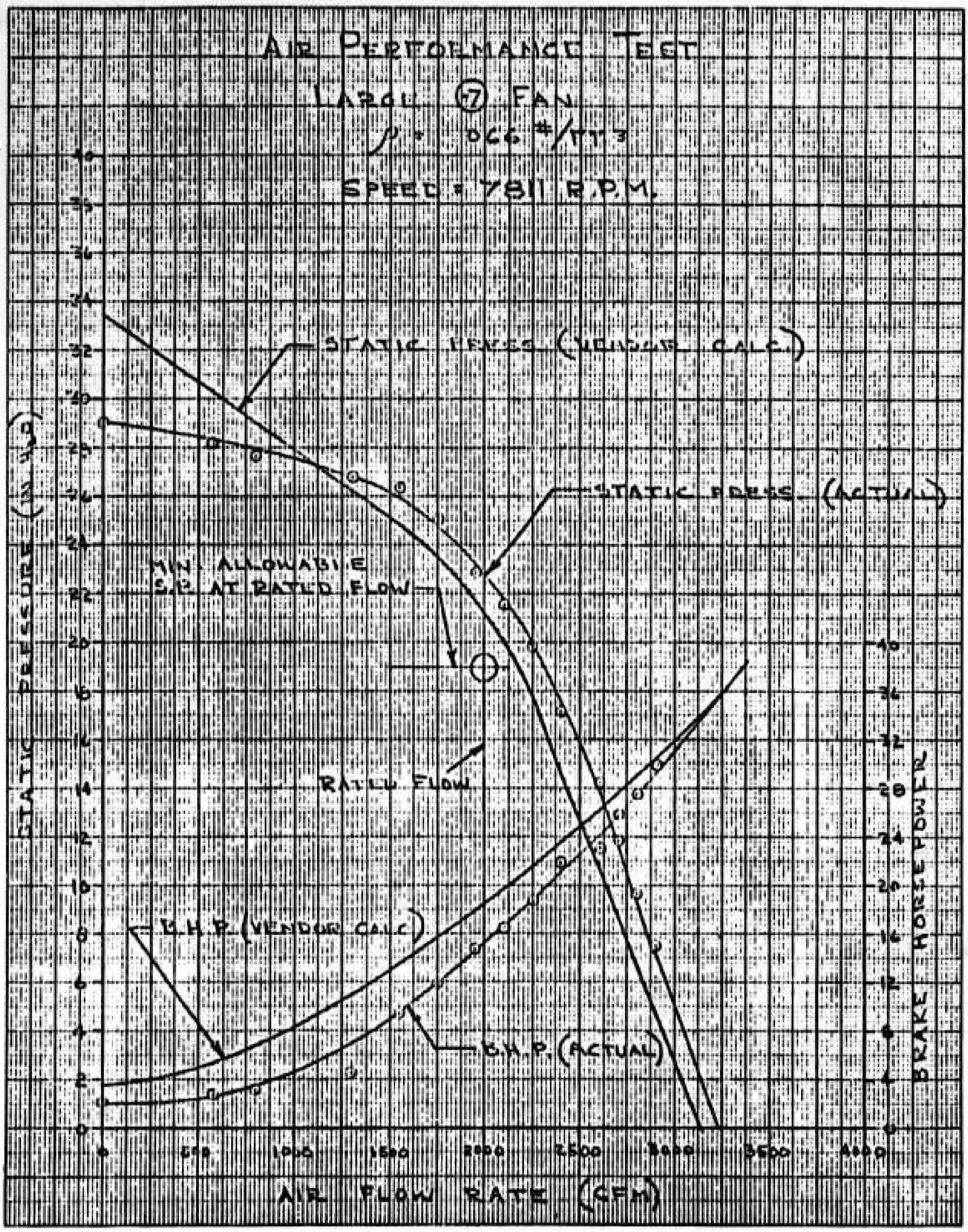

Figure 7.2 Large Cooling Fan Performance - ρ = .066 lbs/ft^3, 7811 RPM

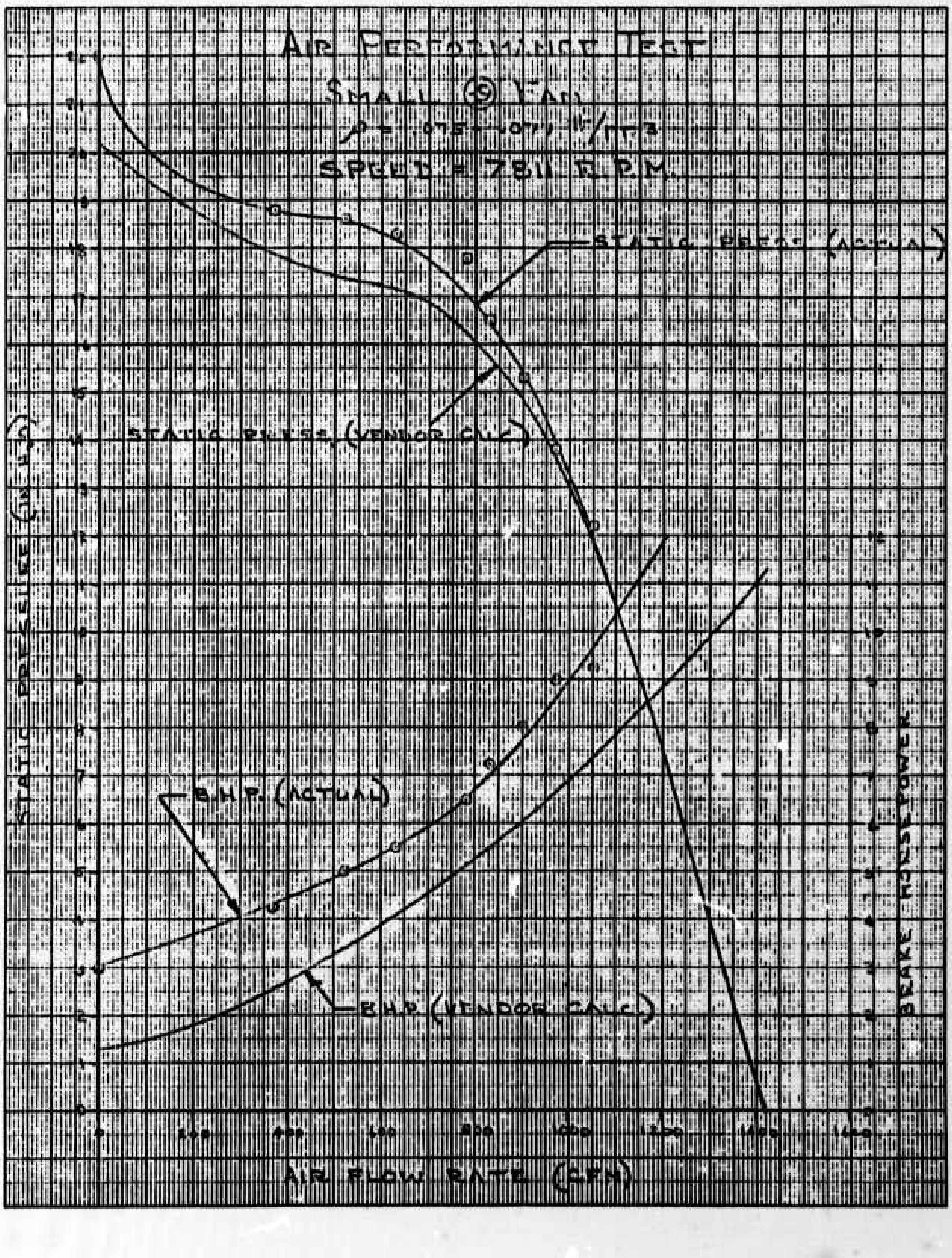

Figure 7.3 **Small Cooling Fan Performance - ρ = .075- .077 lbs/ft^3, 7811 RPM**

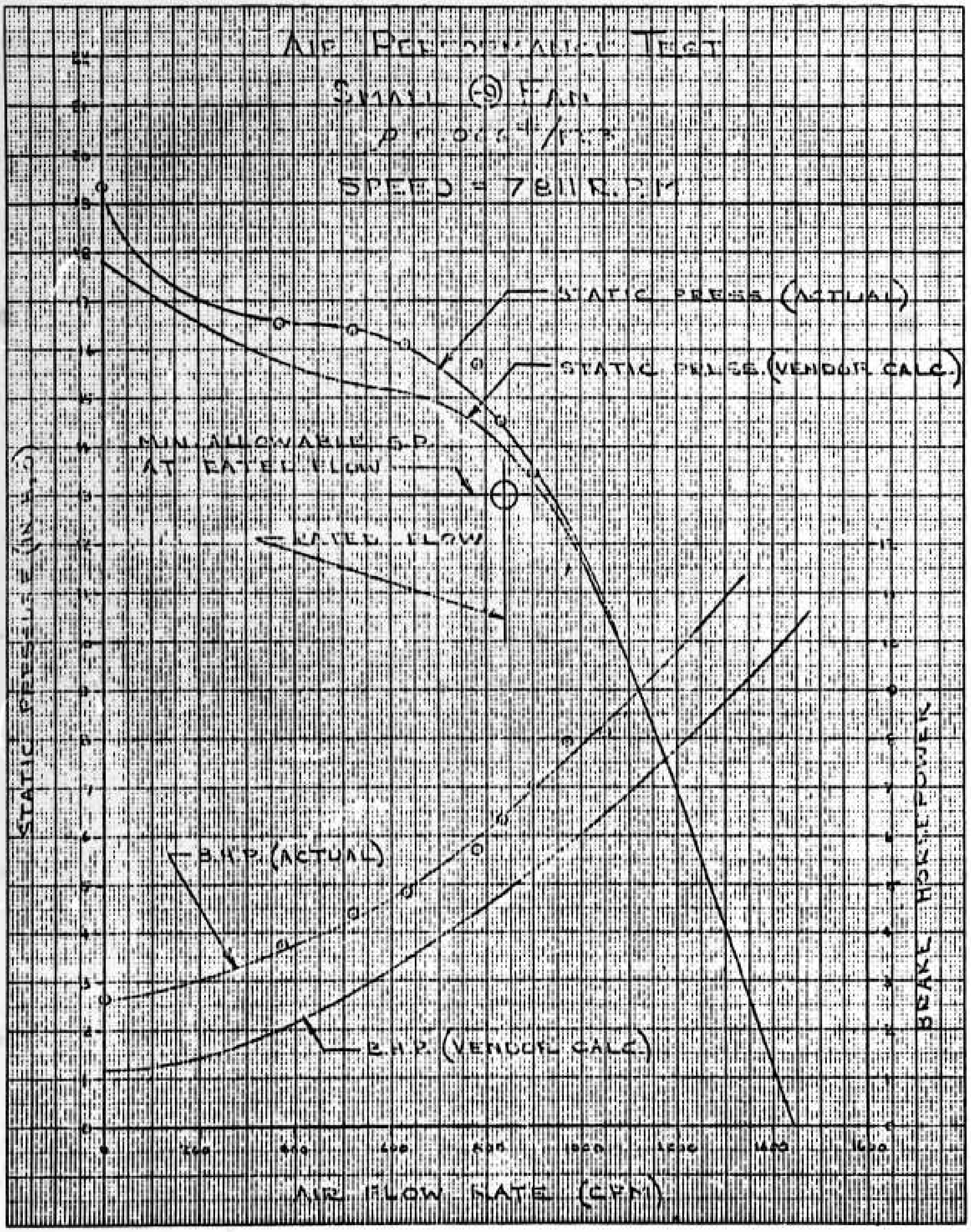

Figure 7.4 Small Cooling Fan Performance - $\rho = .066$ lbs/ft^3, 7811 RPM

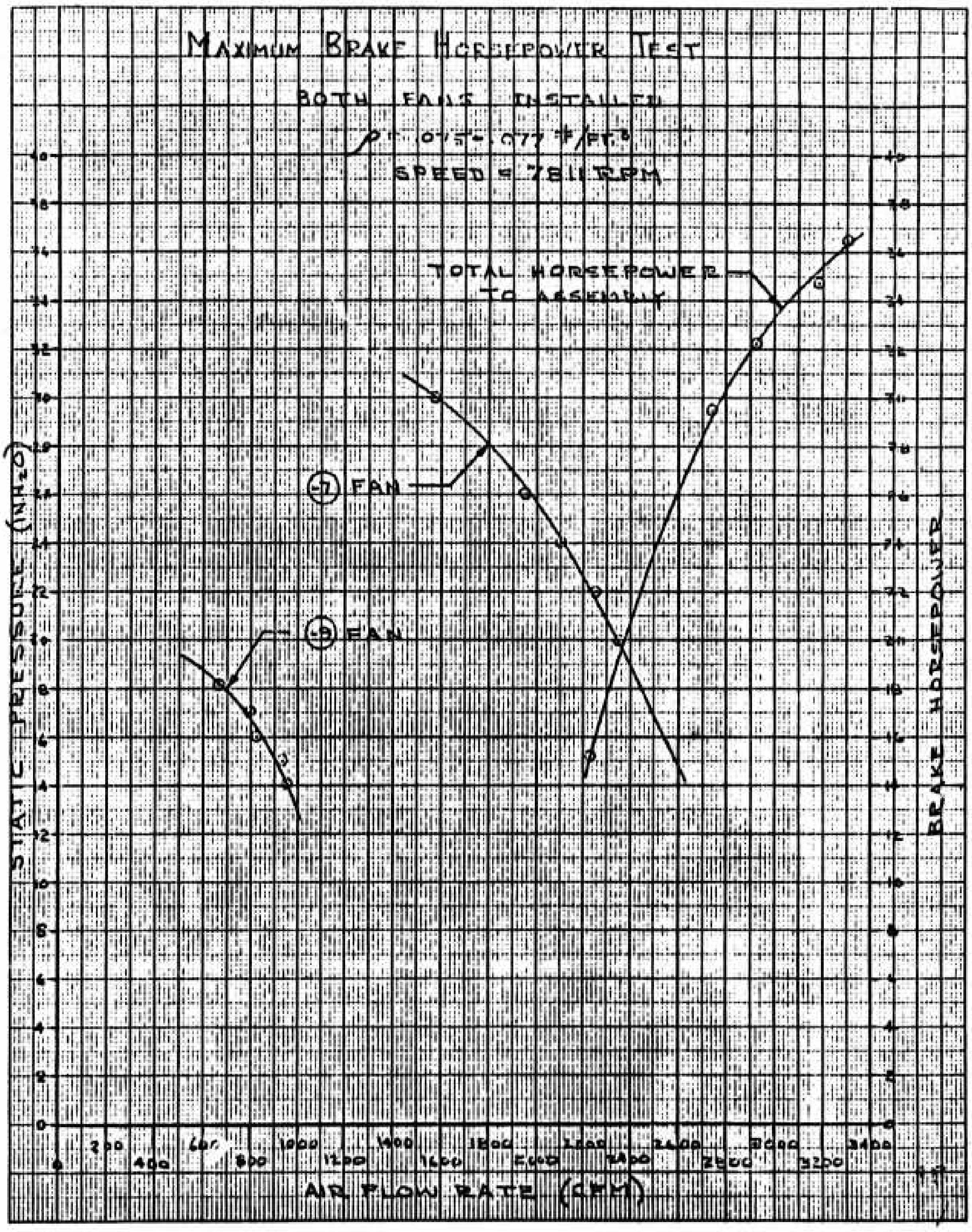

Figure 7.5 Cooling Fan Performance - Maximum Brake Horsepower Test, ρ = .075-.077 lbs/ft^3, 7811 RPM

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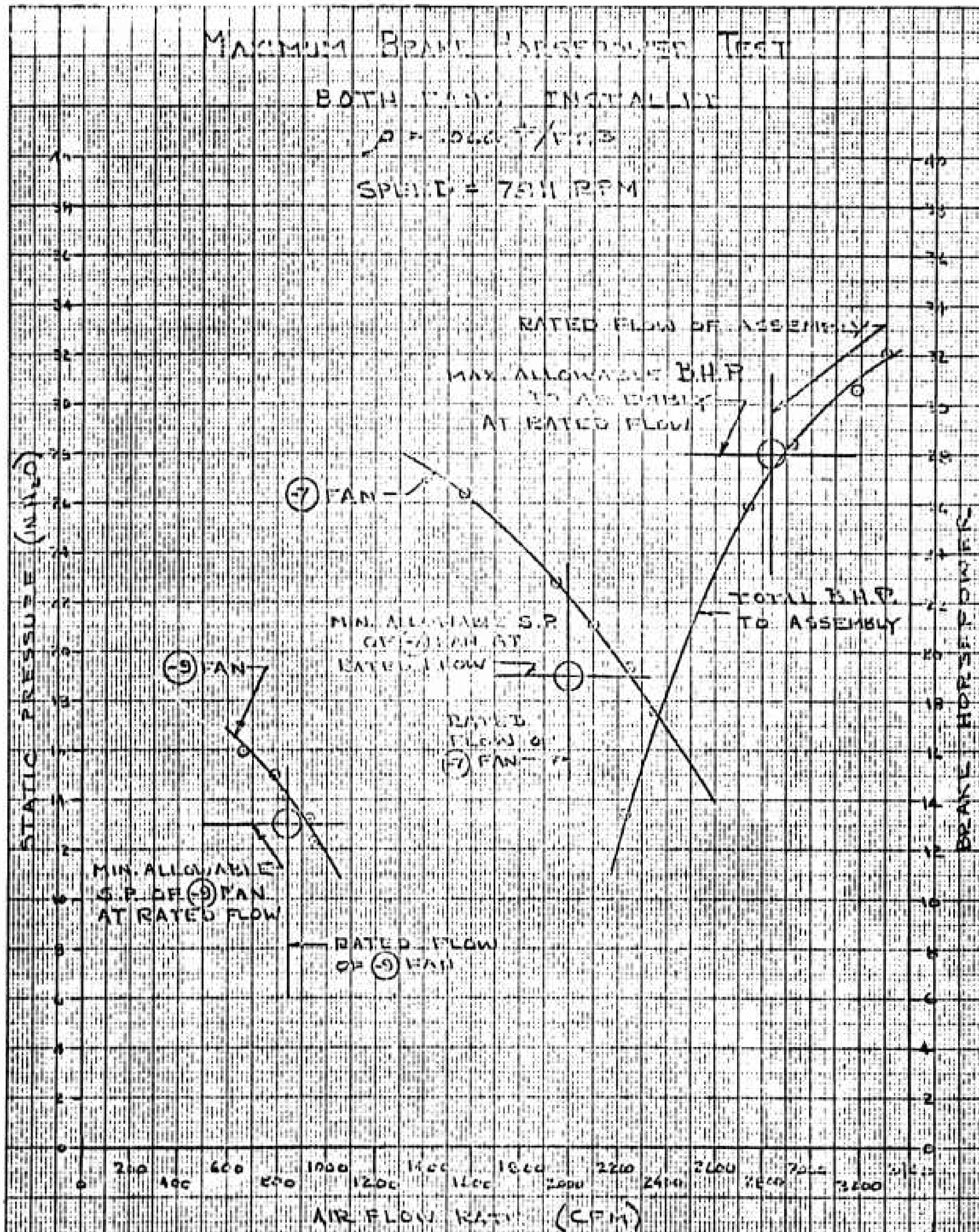

Figure 7.6 Cooling Fan Performance - Maximum Brake Horsepower Test, ρ = .066 lbs/ft^3, 7811 RPM

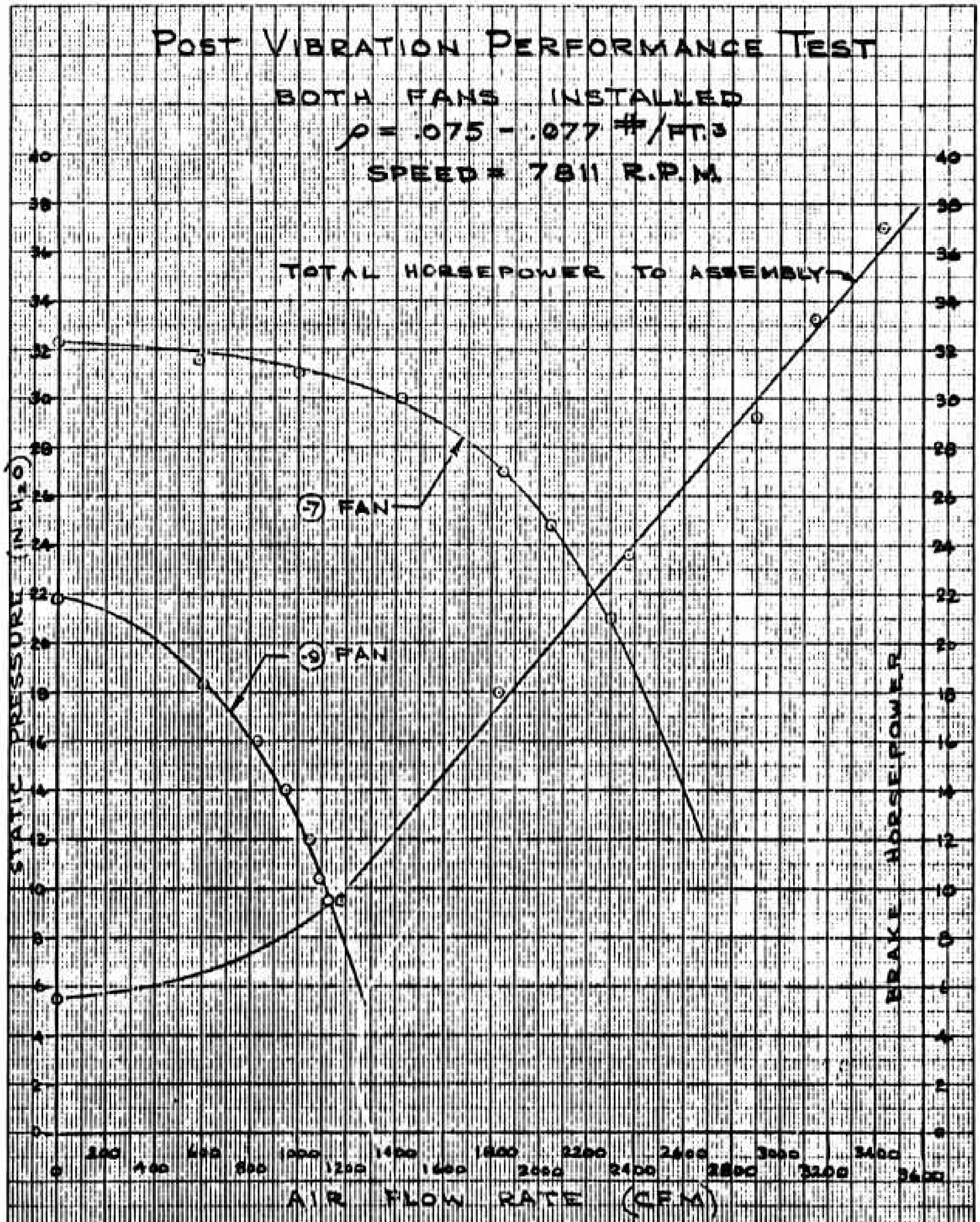

Figure 7.7 Cooling Fan Performance - Post Vibration Test, ρ = .075-.077 lbs/ft^3, 7811 RPM

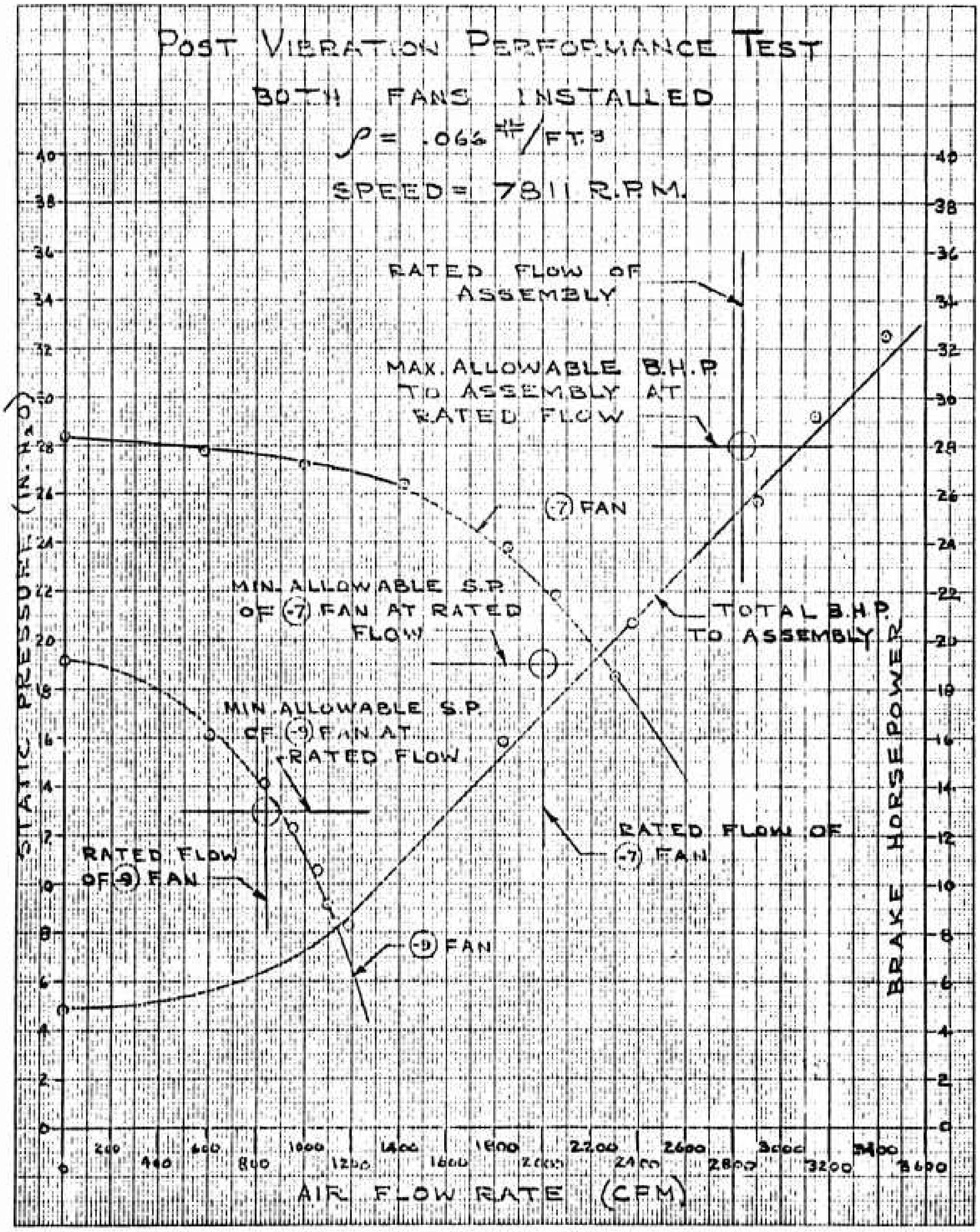

Figure 7.8 Cooling Fan Performance - Post Vibration Test, $\rho = .066\ lbs/ft^3$, 7811 RPM

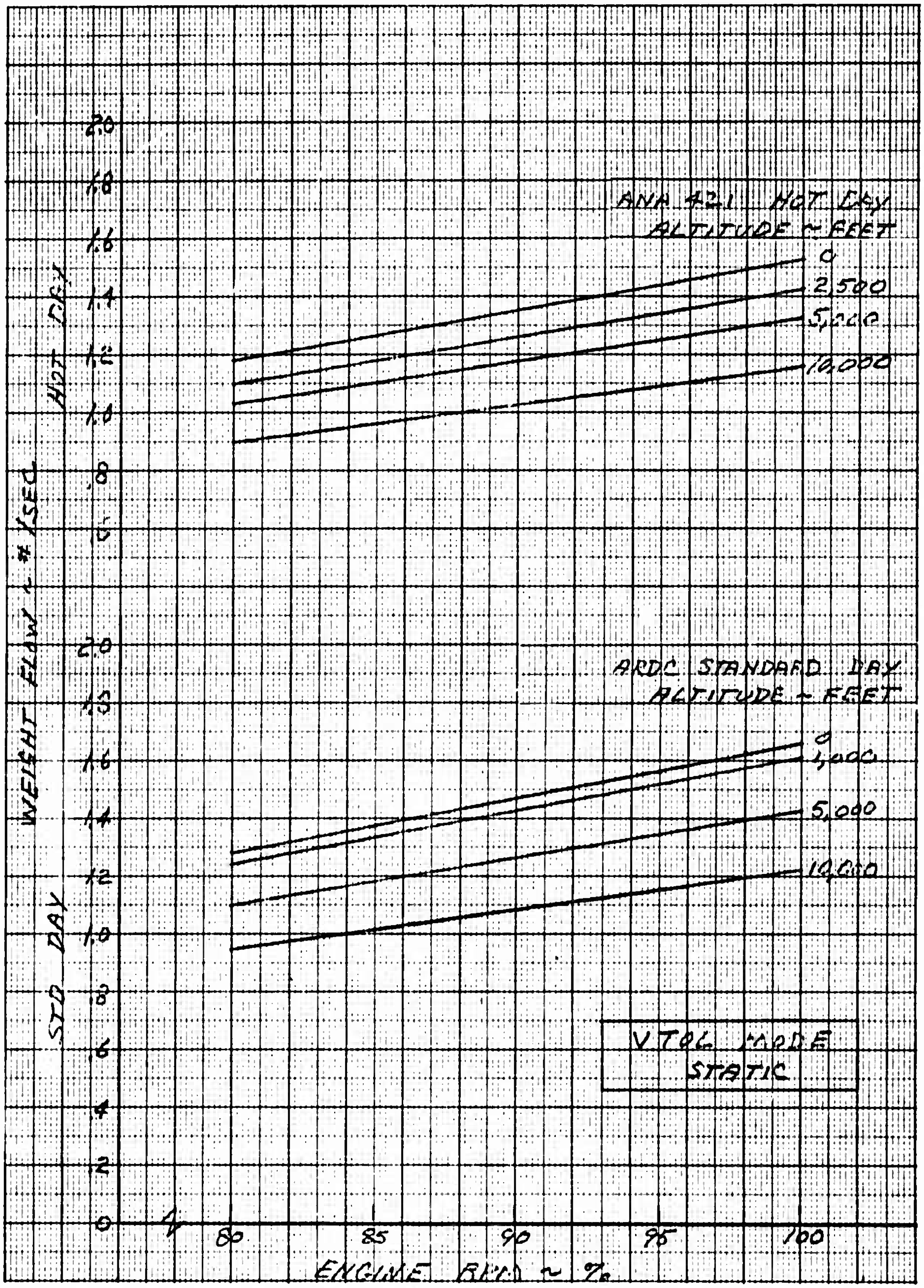

Figure 7.9 Cooling Air Weight Flow - Cockpit to Cooling Fan Compartment Vs % RPM and Altitude - Fan Mode, Standard Day

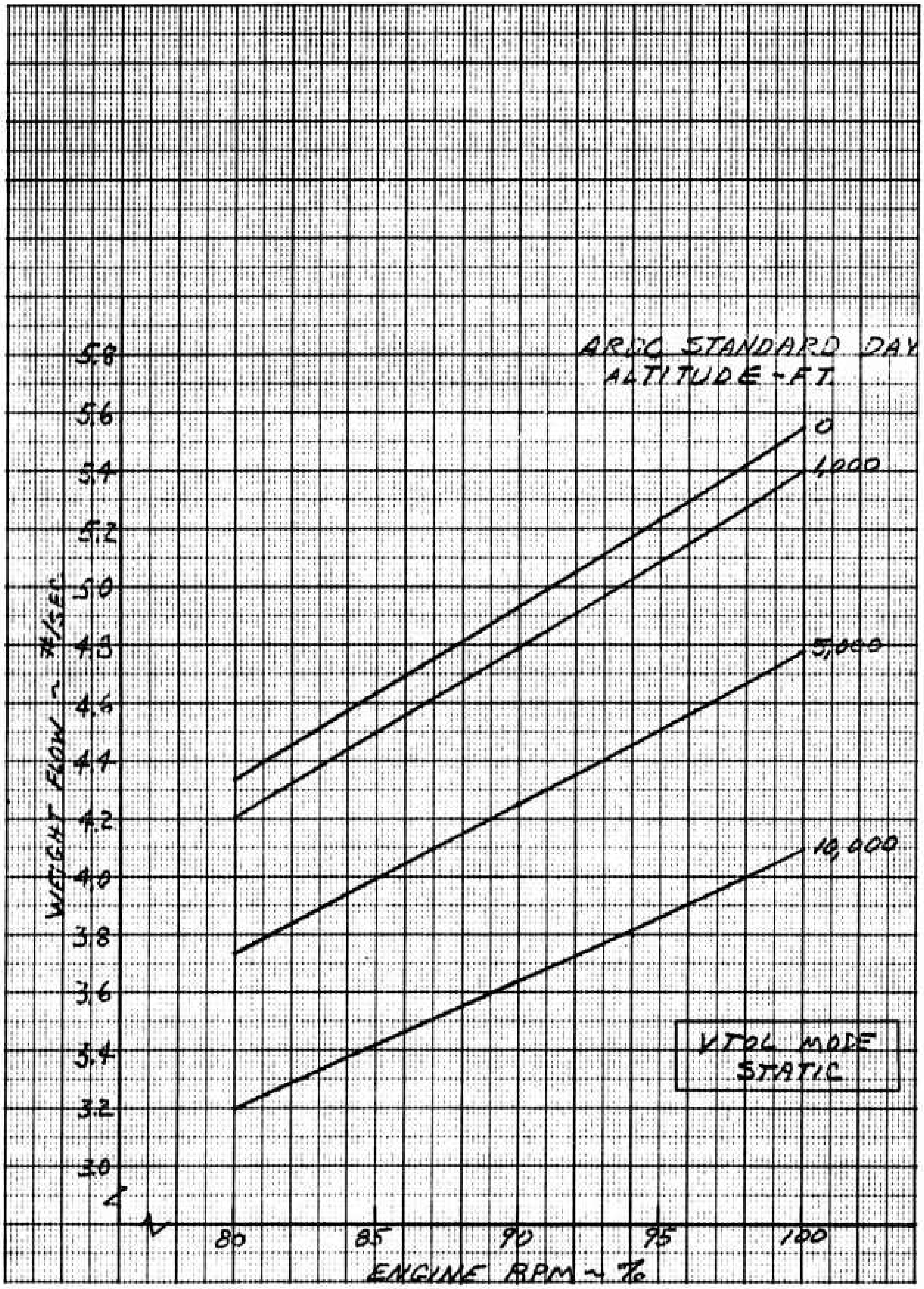

Figure 7.10 Cooling Air Weight Flow - Fuselage Ports to Cooling Fan Compartment Vs % RPM and Altitude - Fan Mode, Standard Day

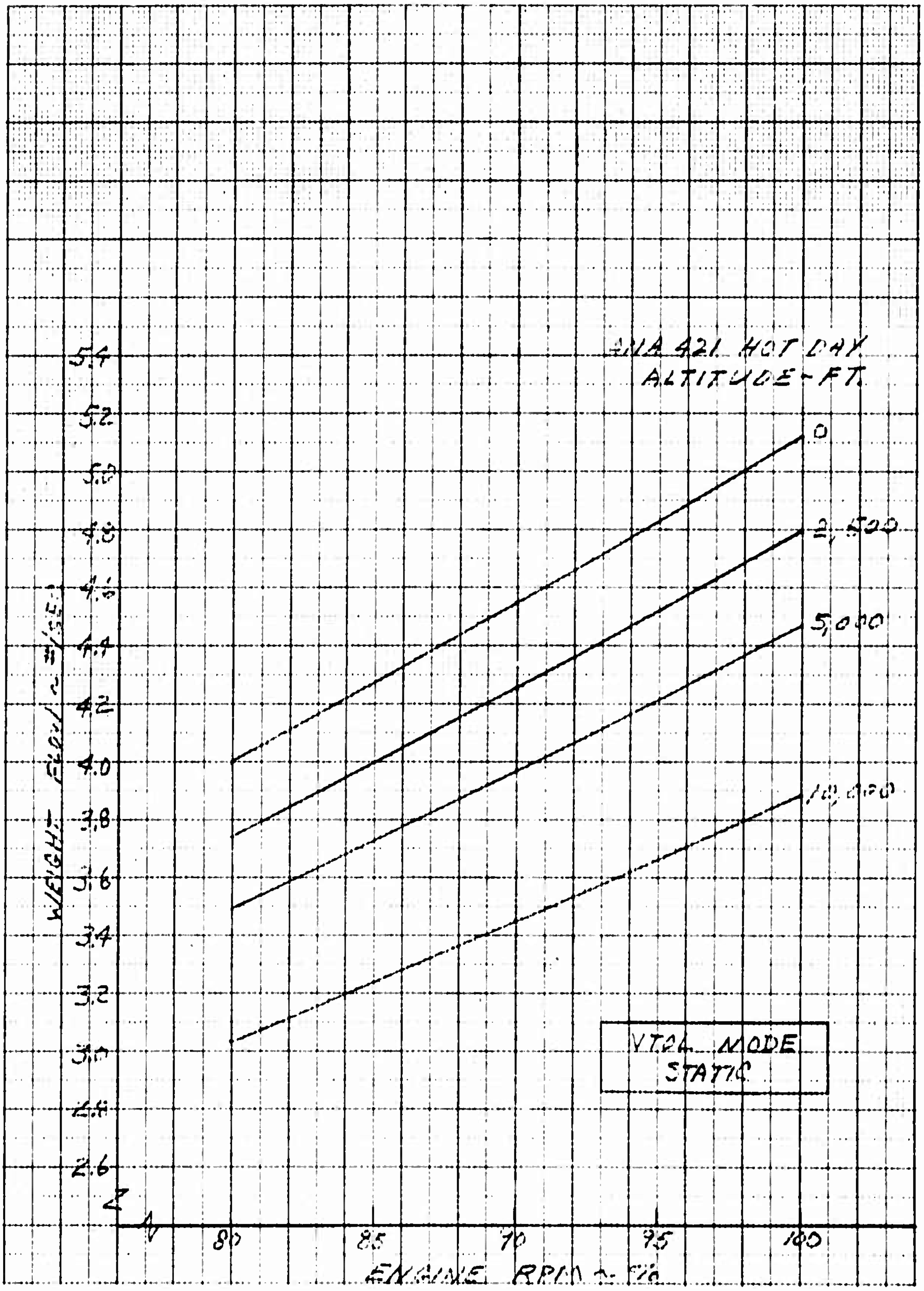

Figure 7.11 Cooling Air Weight Flow - Fuselage Ports to Cooling Fan Compartment Vs % RPM and Altitude - Fan Mode, Hot Day

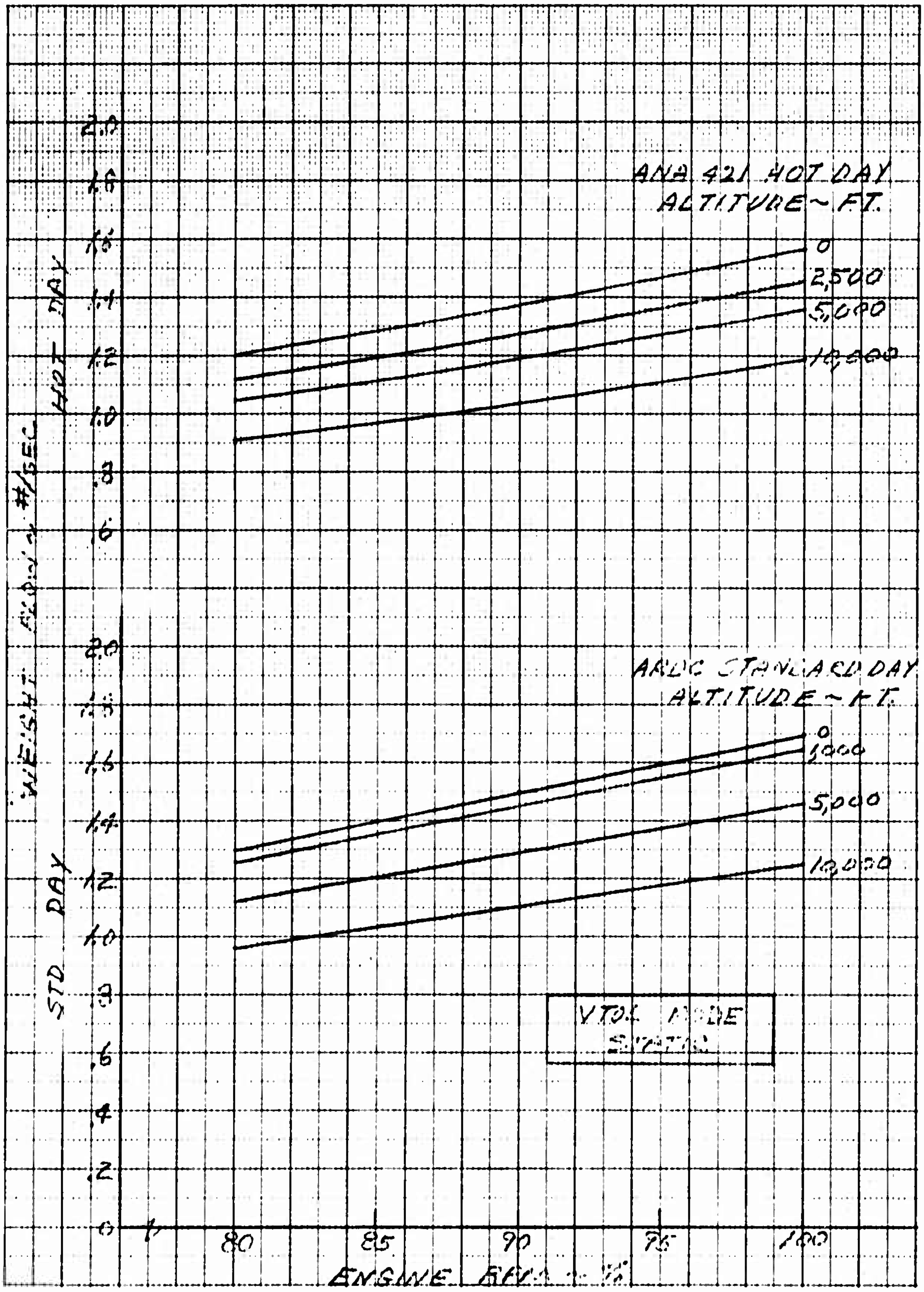

Figure 7.12 Cooling Air Weight Flow - Small Cooling Fans to Electronic Compartment Vs % RPM and Altitude - Fan Mode, Standard and Hot Day

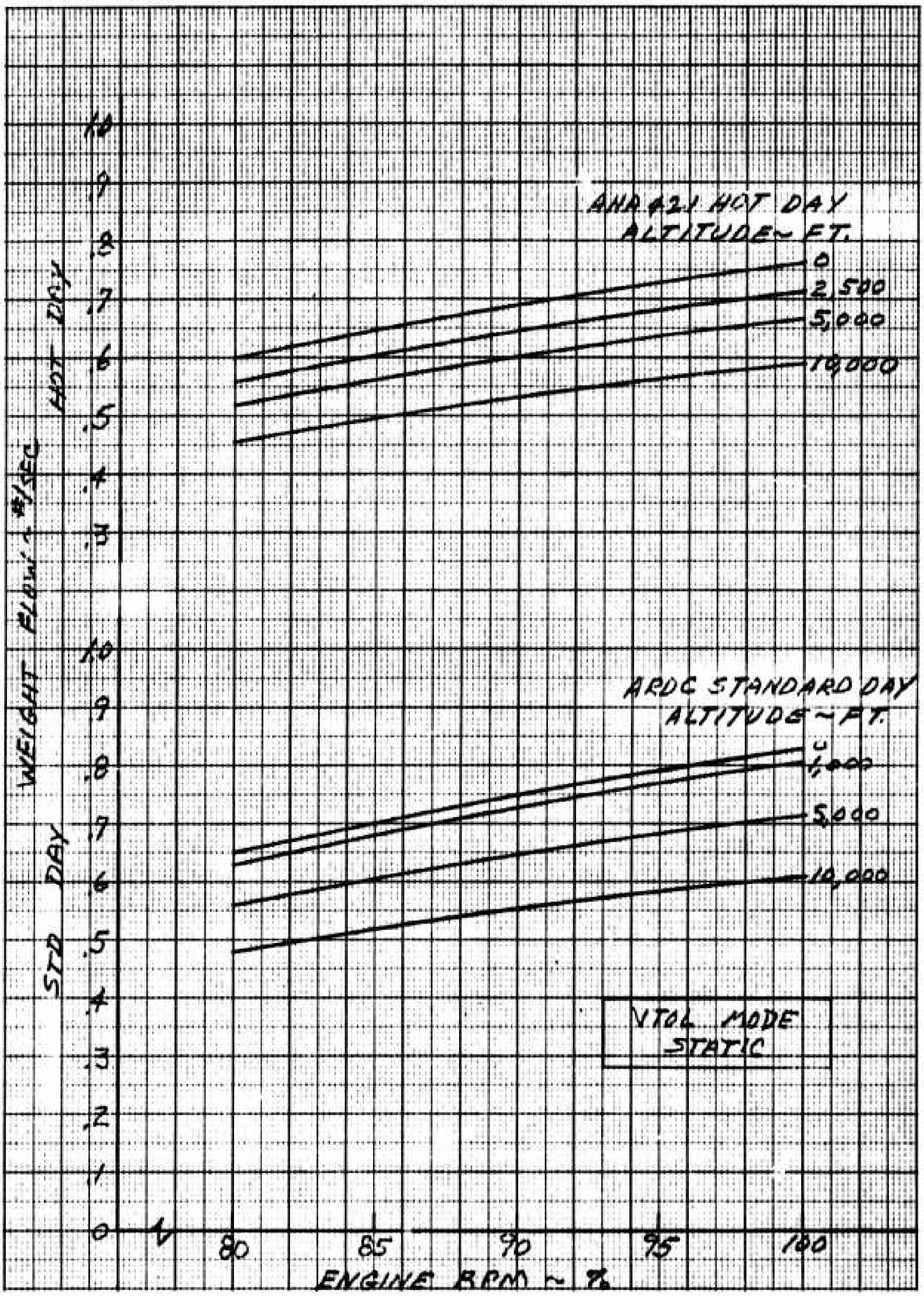

Figure 7.13 Cooling Air Weight Flow - Small Cooling Fans to Generators Vs % RPM and Altitude - Fan Mode, Standard and Hot Day

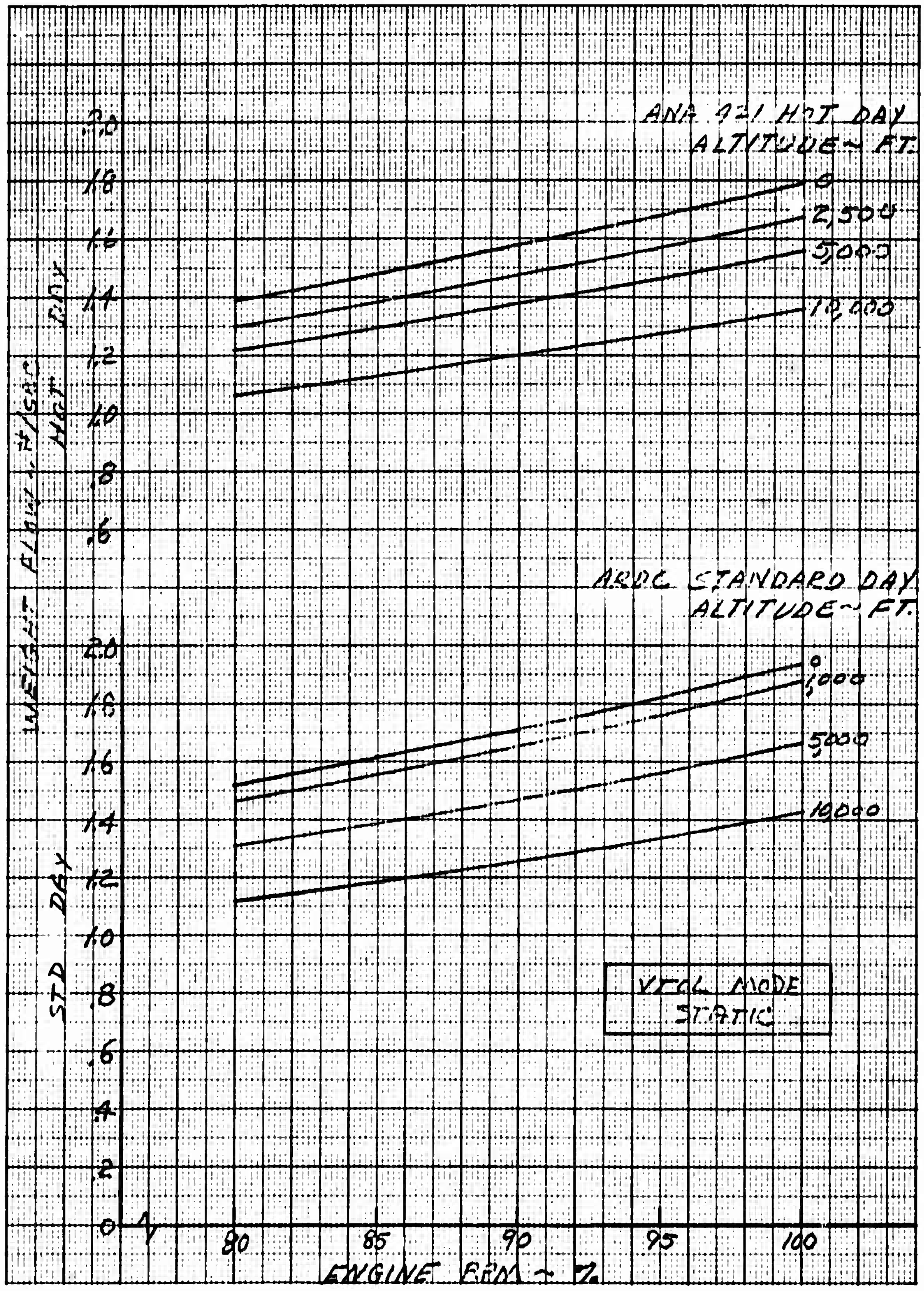

Figure 7.14 Cooling Air Weight Flow - L.H. Large Cooling Fan to Center Fuselage Vs % RPM and Altitude - Fan Mode, Standard and Hot Day

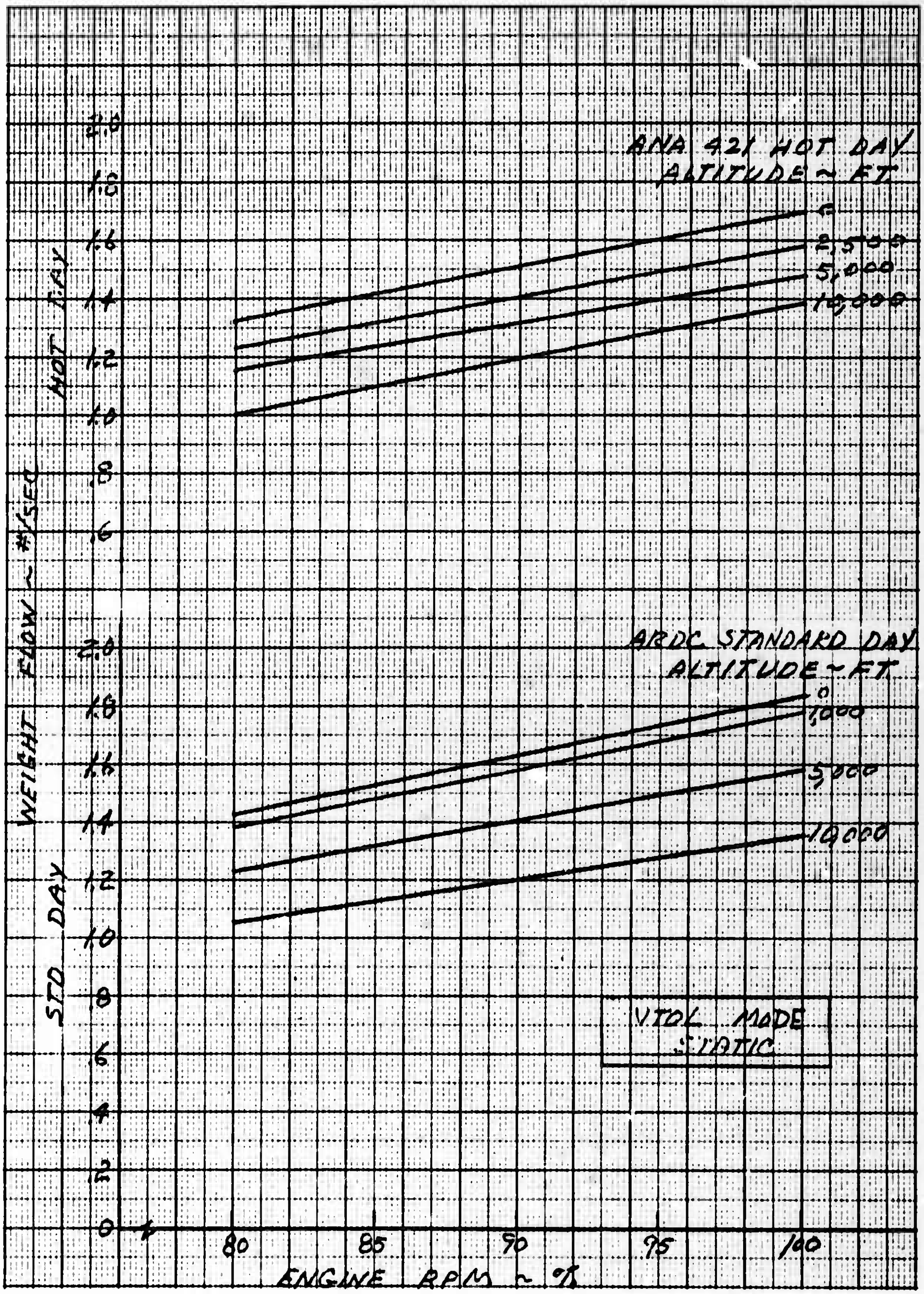

Figure 7.15 Cooling Air Weight Flow - R.H. Large Cooling Fan to Center Fuselage Vs % RPM and Altitude - Fan Mode, Standard and Hot Day

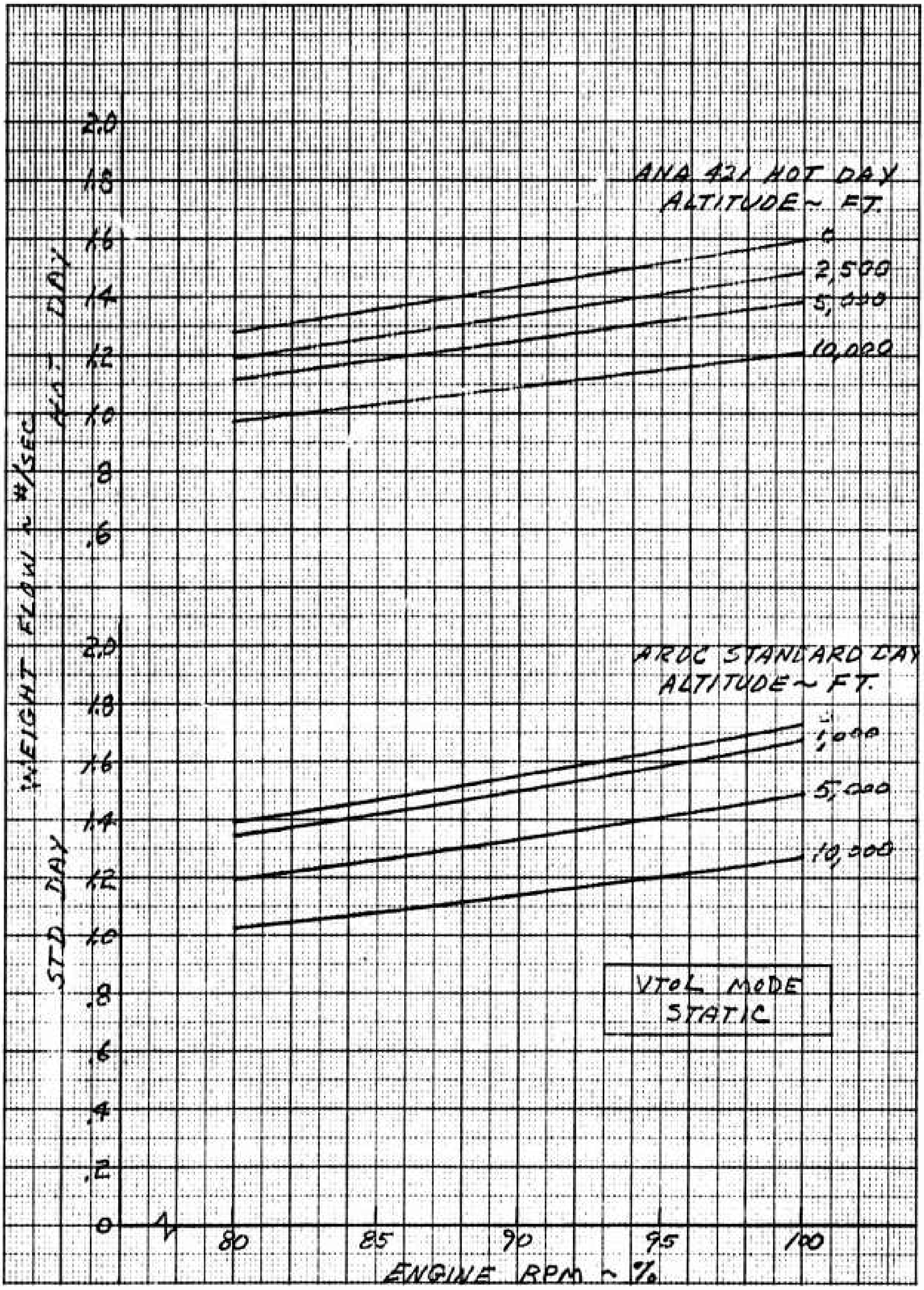

Figure 7.16 Cooling Air Weight Flow - Large Cooling Fans to Tailpipe Ejectors Vs % RPM and Altitude - Fan Mode, Standard and Hot Day

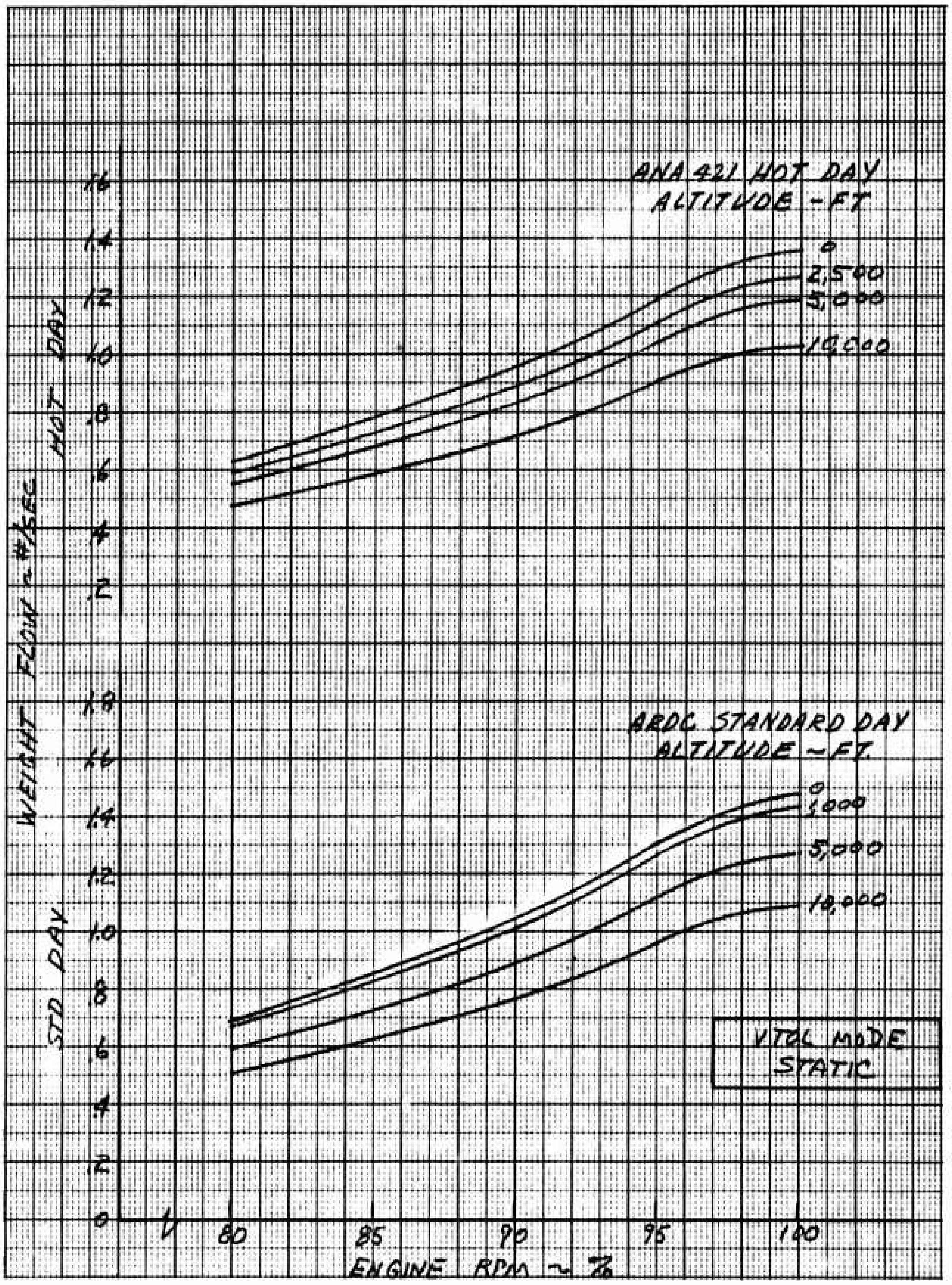

Figure 7.17 Cooling Air Weight Flow - Center Fuselage to Wing Fan Cavities Vs % RPM and Altitude - Fan Mode, Standard and Hot Day

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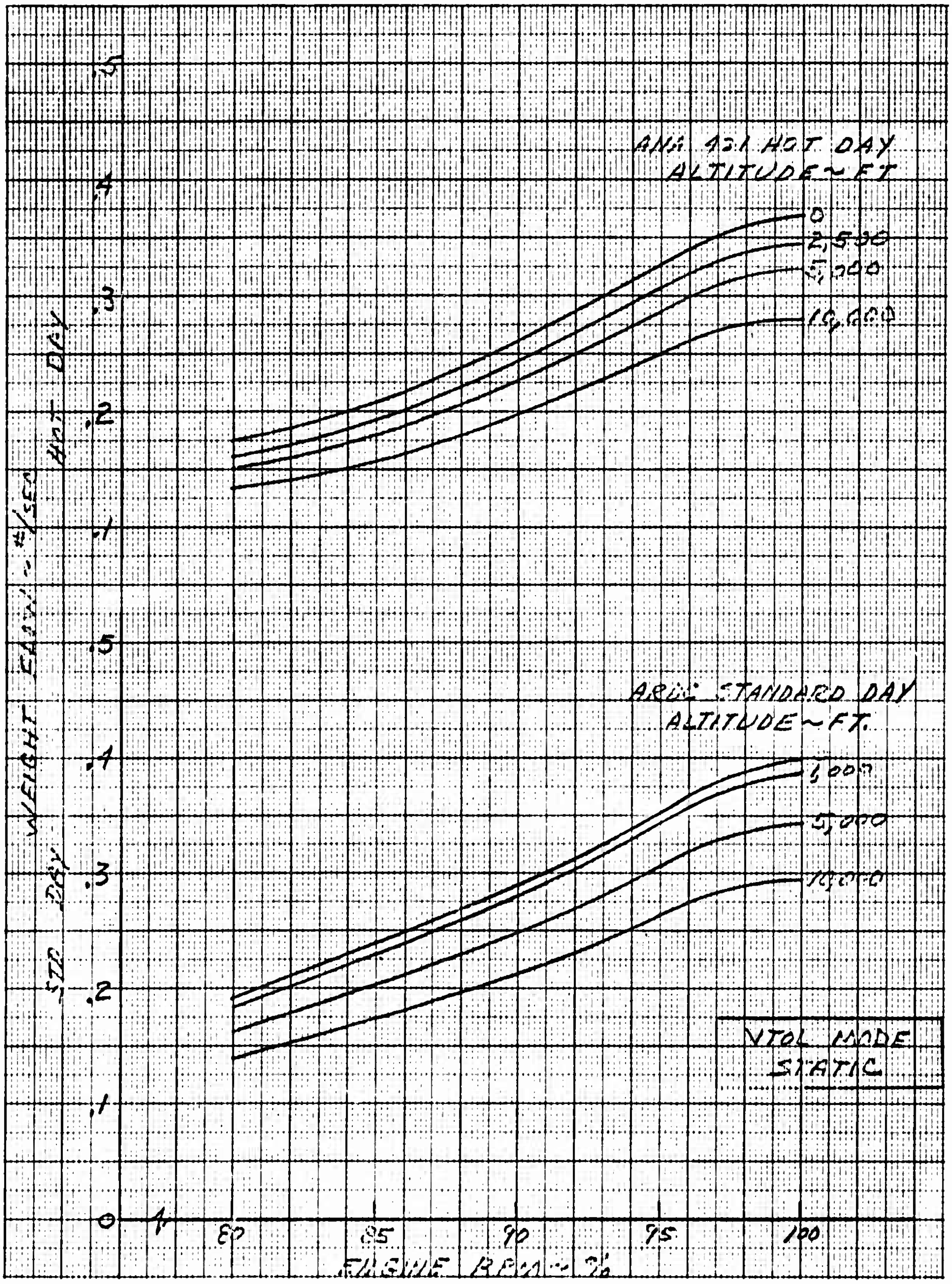

Figure 7.18 Cooling Air Weight Flow - Forward Fuselage to Nose Fan Cavity Vs % RPM and Altitude - Fan Mode, Standard and Hot Day

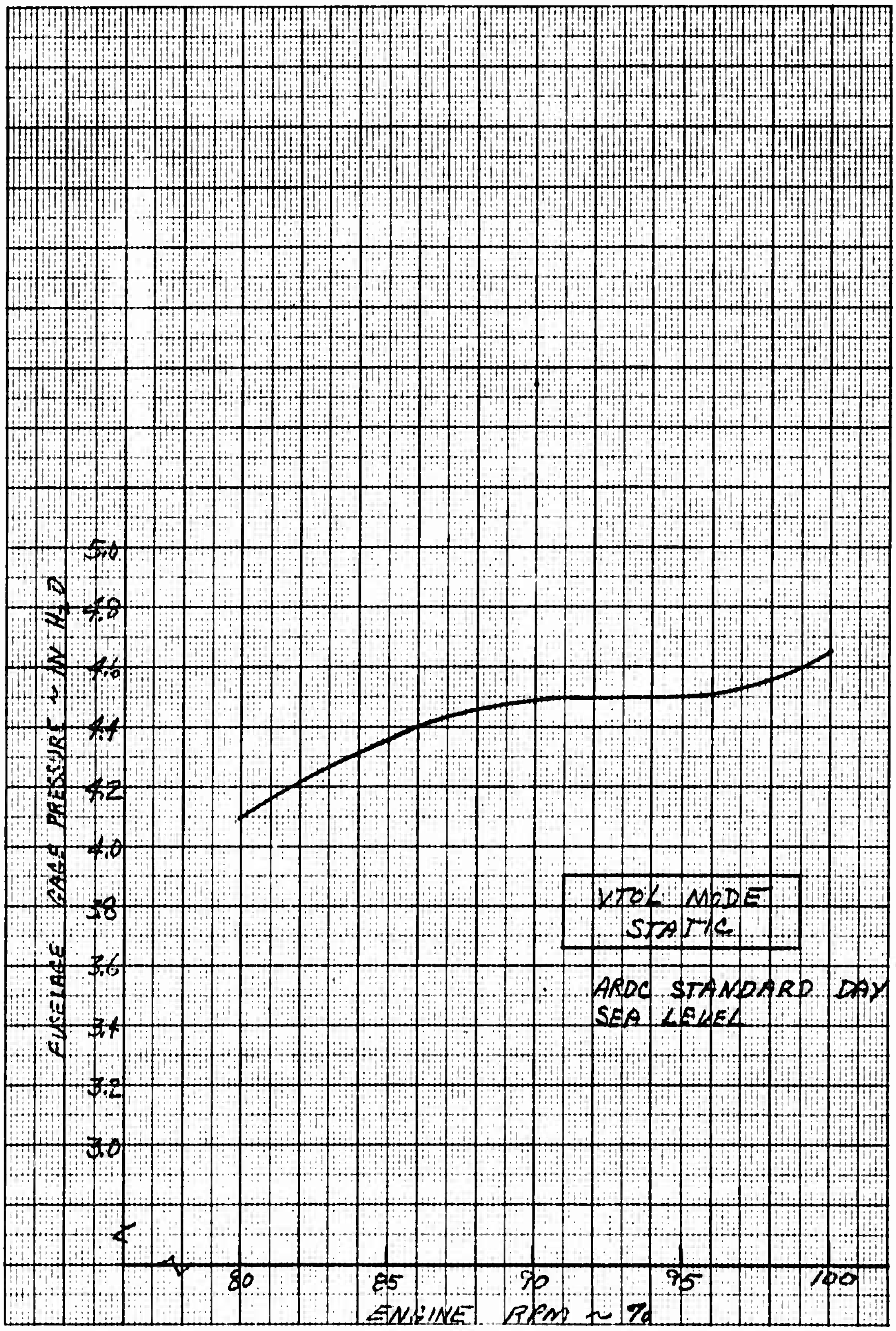

Figure 7.19 Center Fuselage Gage Pressure Vs % RPM - Fan Mode, Standard Day, Sea Level

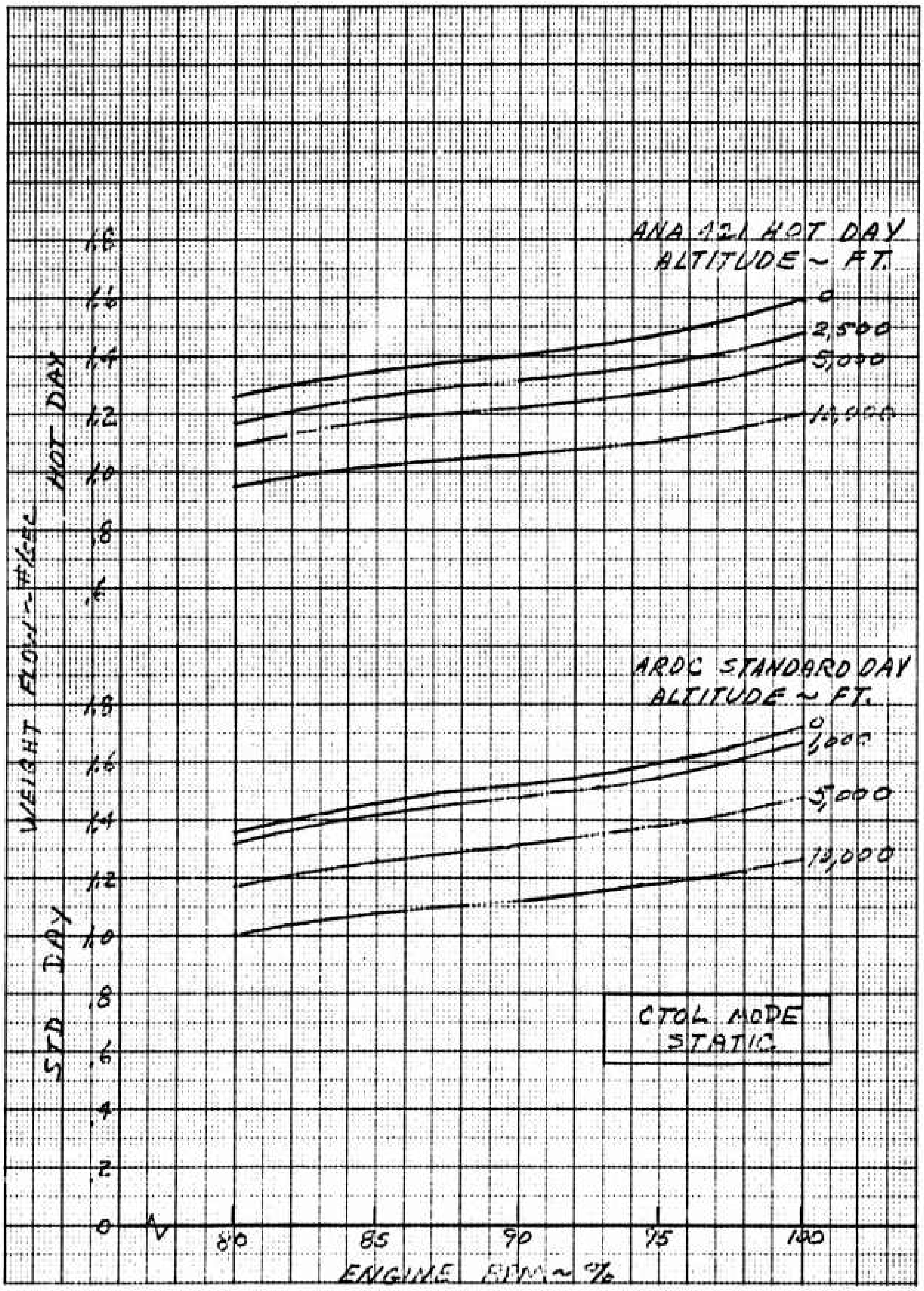

Figure 7.20 Cooling Air Weight Flow - Cockpit to Cooling Fan Compartment Vs % RPM and Altitude - Conventional Mode, Standard and Hot Day

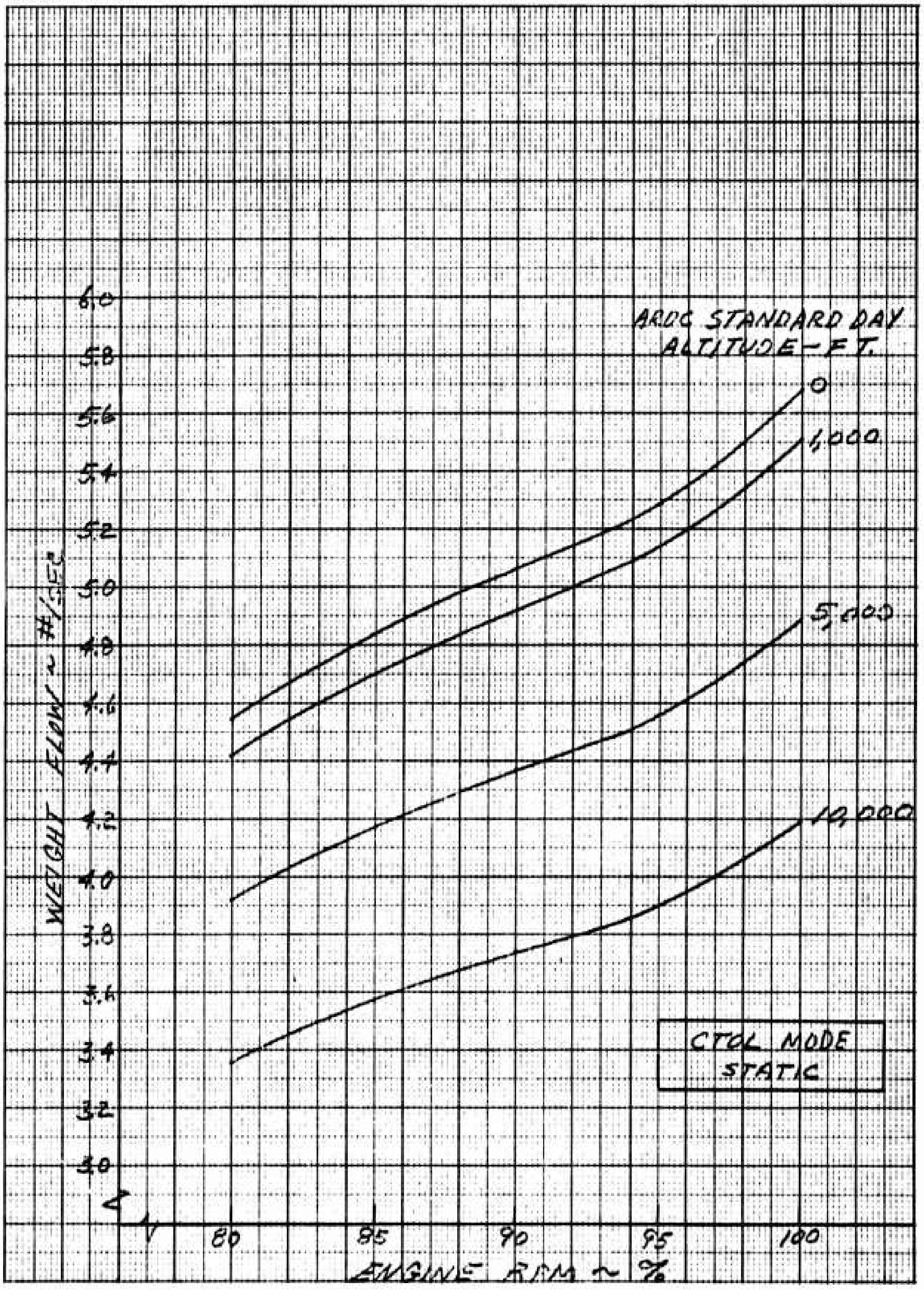

Figure 7.21 Cooling Air Weight Flow - Fuselage Ports to Cooling Fan Compartment Vs % RPM and Altitude - Conventional Mode, Standard Day

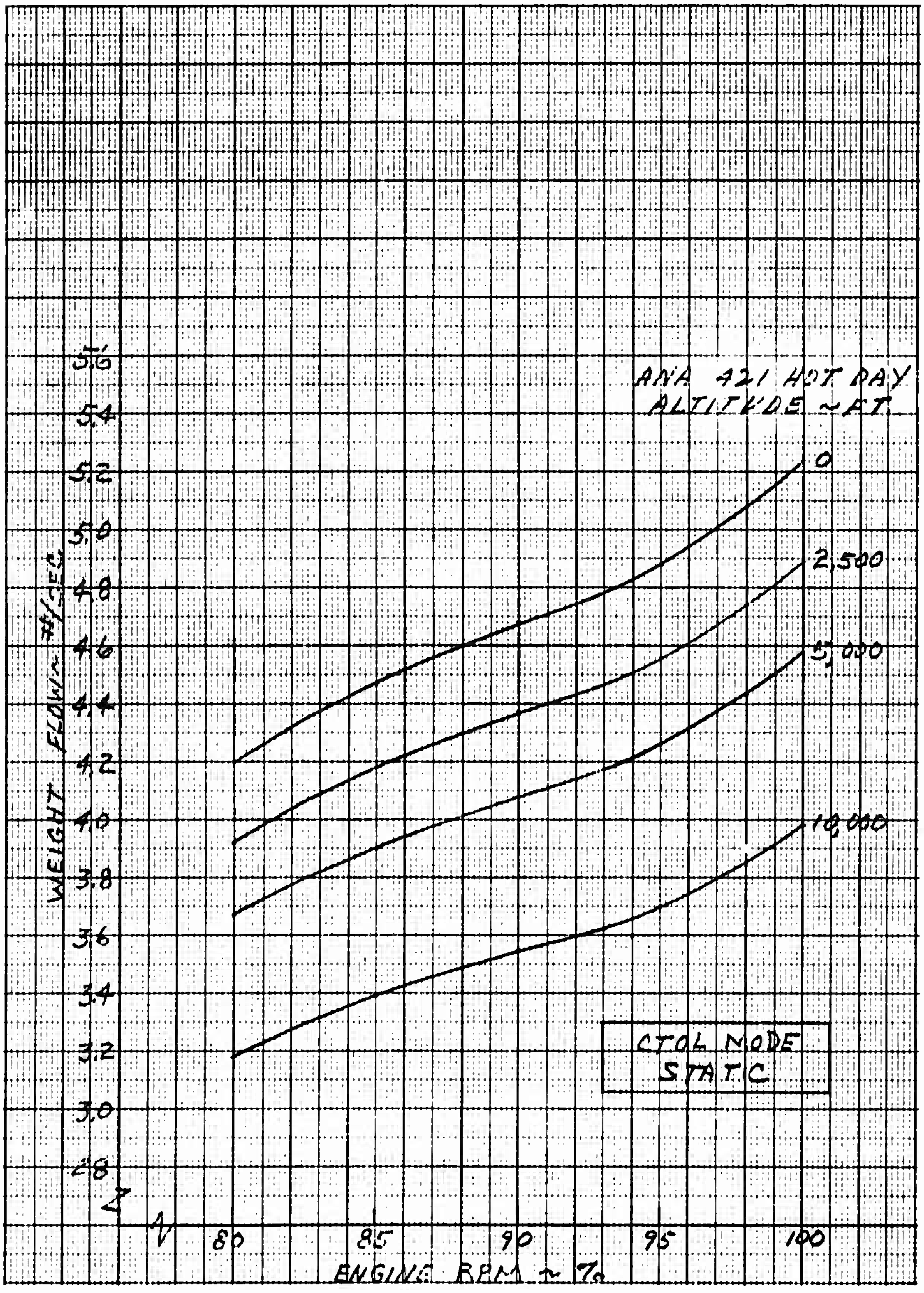

Figure 7.22 Cooling Air Weight Flow - Fuselage Ports to Cooling Fan Compartment Vs % RPM and Altitude - Conventional Mode, Hot Day

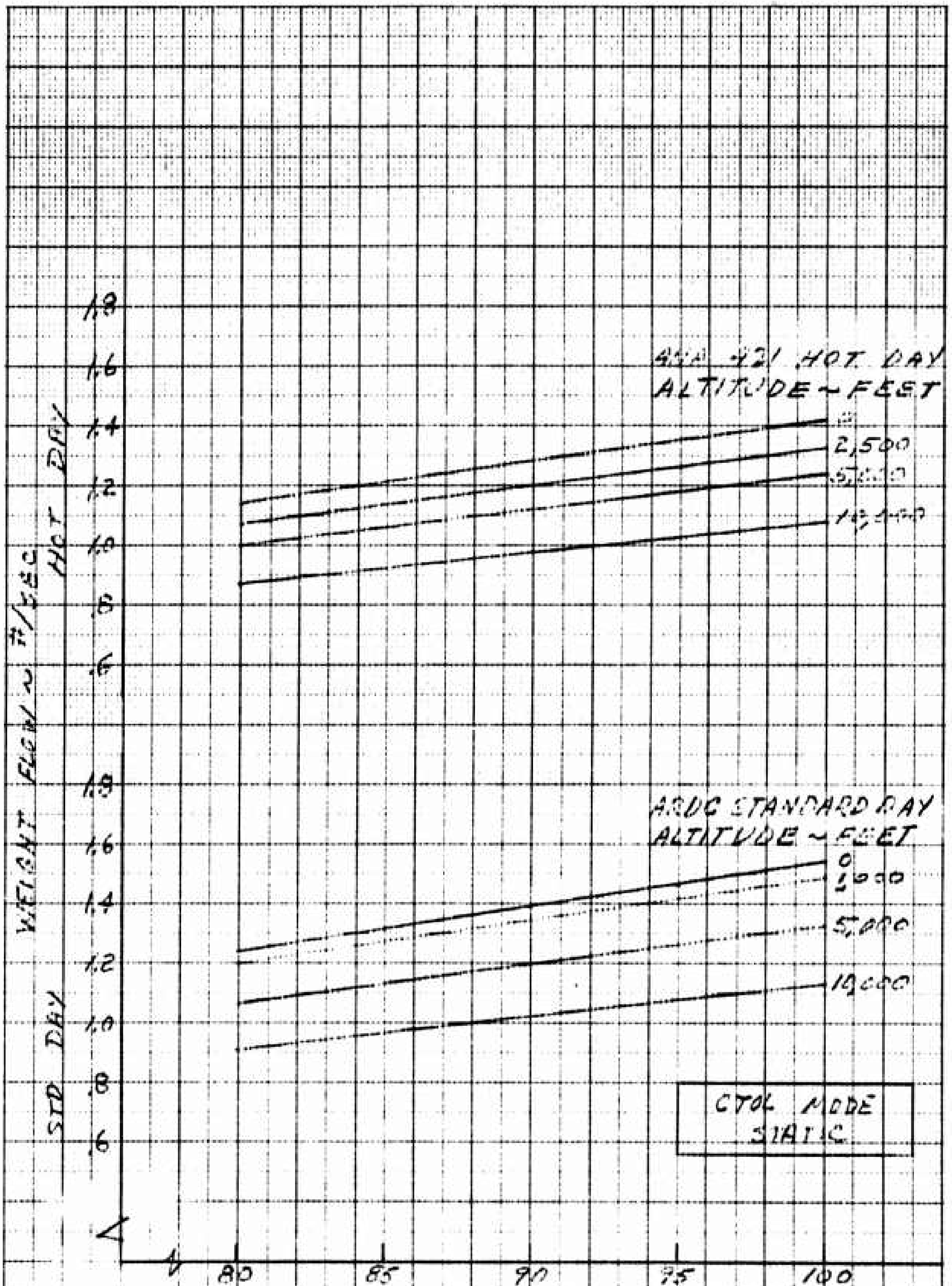

Figure 7.23 Cooling Air Weight Flow - Small Cooling Fans to Electronic Compartment Vs % RPM and Altitude - Conventional Mode, Standard and Hot Day

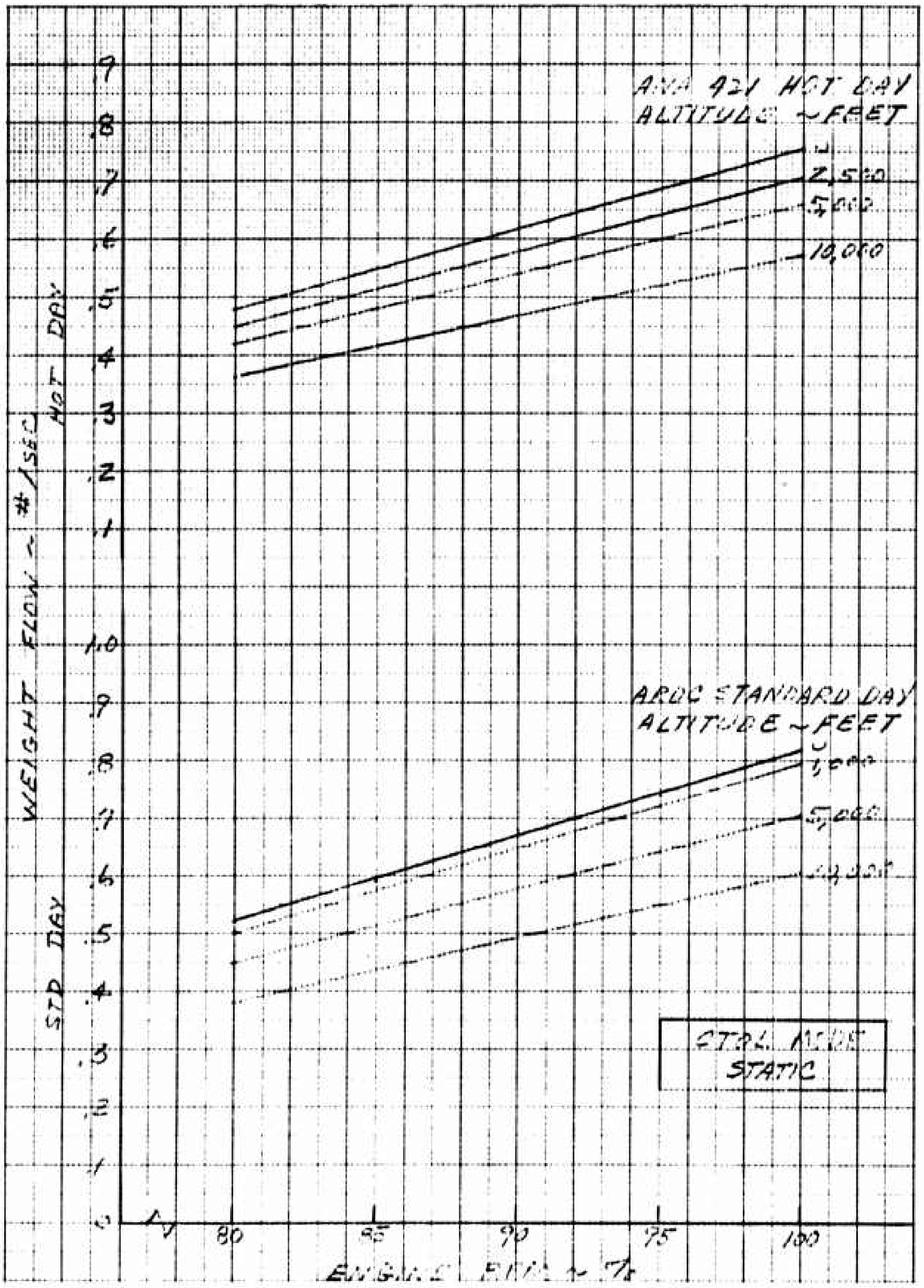

Figure 7.24 Cooling Air Weight Flow - Small Cooling Fans to Generator Vs % RPM and Altitude - Conventional Mode, Standard and Hot Day

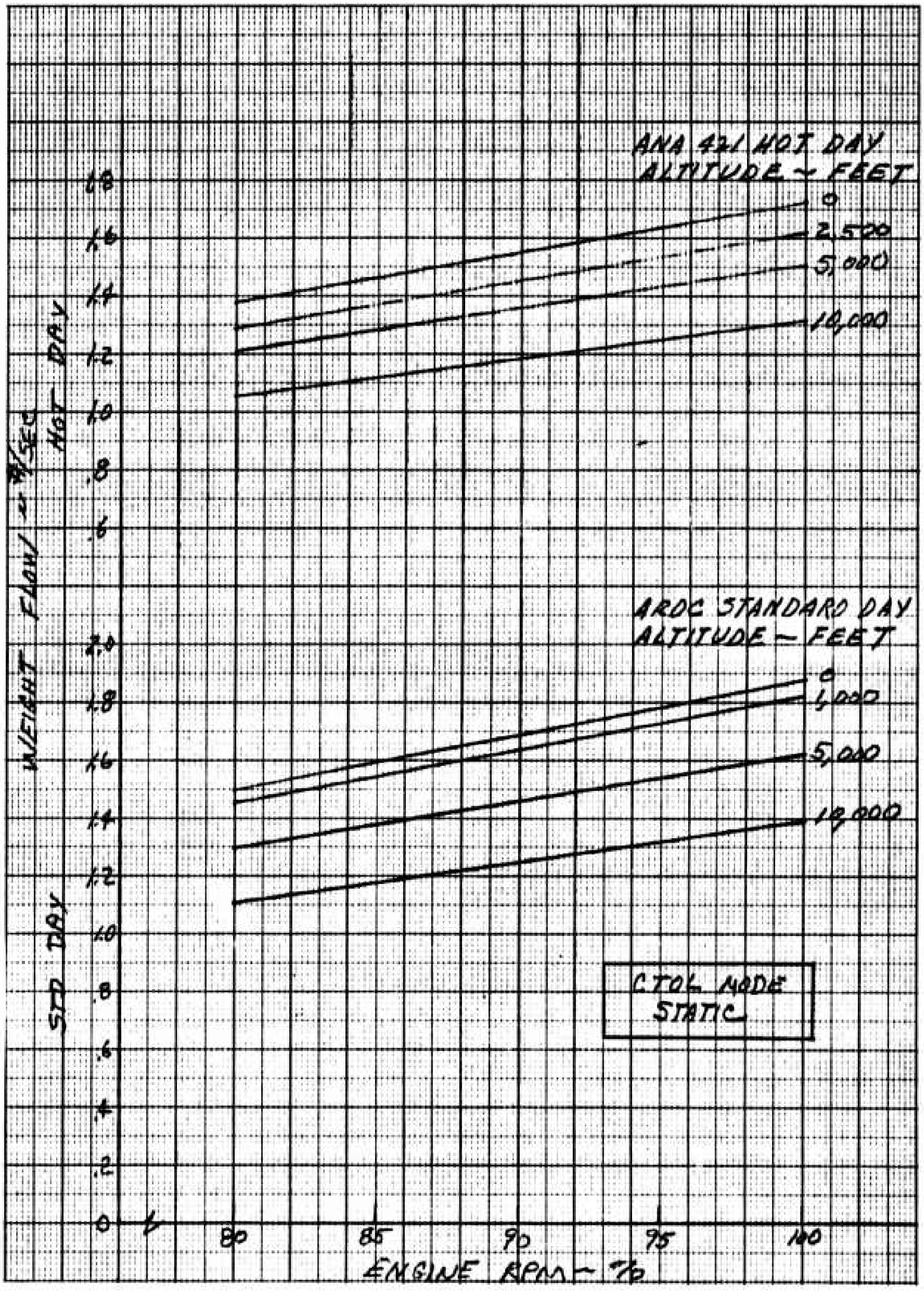

Figure 7.25 Cooling Air Weight Flow - L. H. Large Cooling Fan to Center Fuselage Vs % RPM and Altitude - Conventional Mode, Standard and Hot Day

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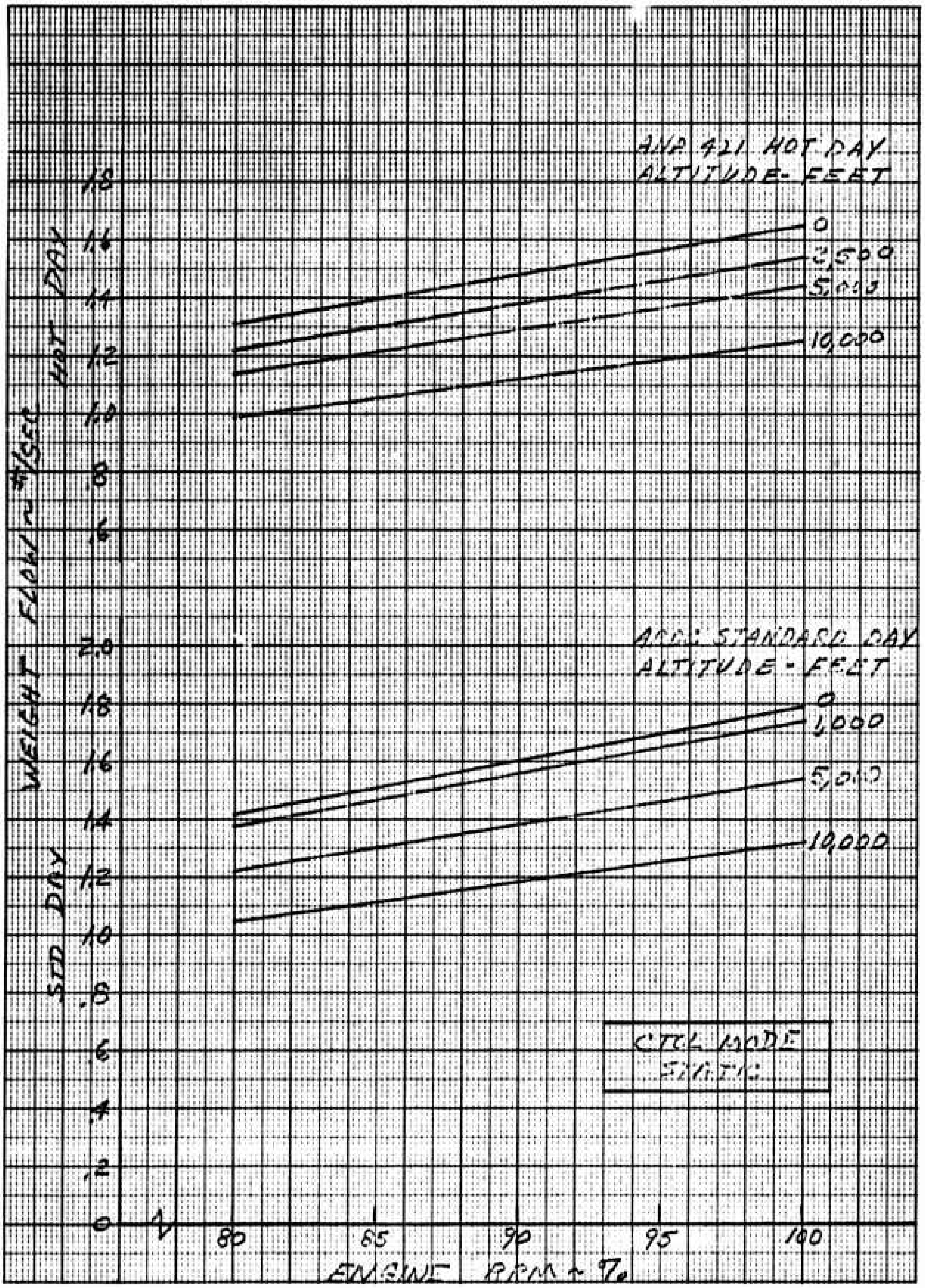

Figure 7.26 Cooling Air Weight Flow - R.H. Large Cooling Fan to Center Fuselage Vs % RPM and Altitude - Conventional Mode, Standard and Hot Day

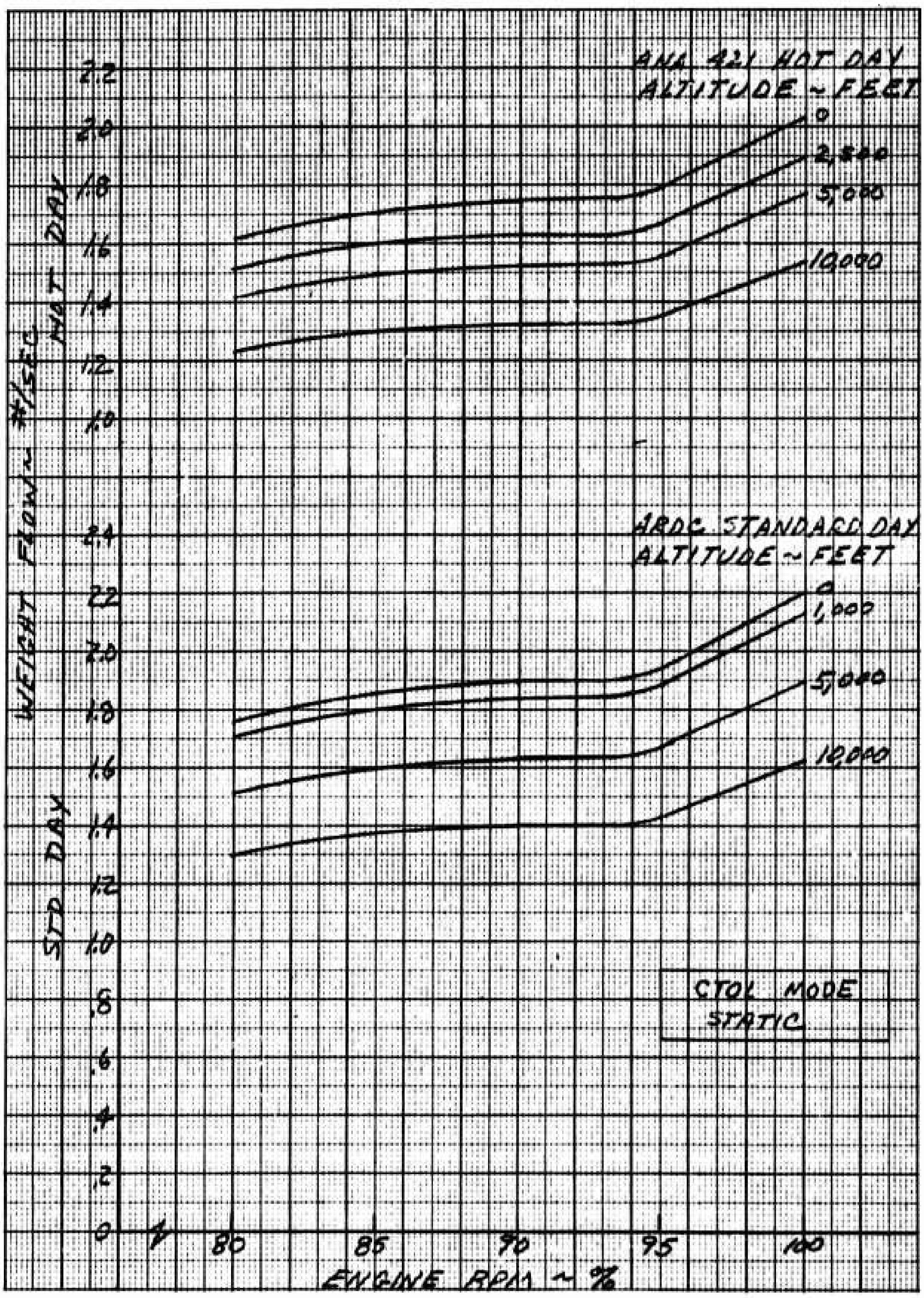

Figure 7.27 Cooling Air Weight Flow - Large Cooling Fans to Tailpipe Ejector Vs % RPM and Altitude - Conventional Mode, Standard and Hot Day

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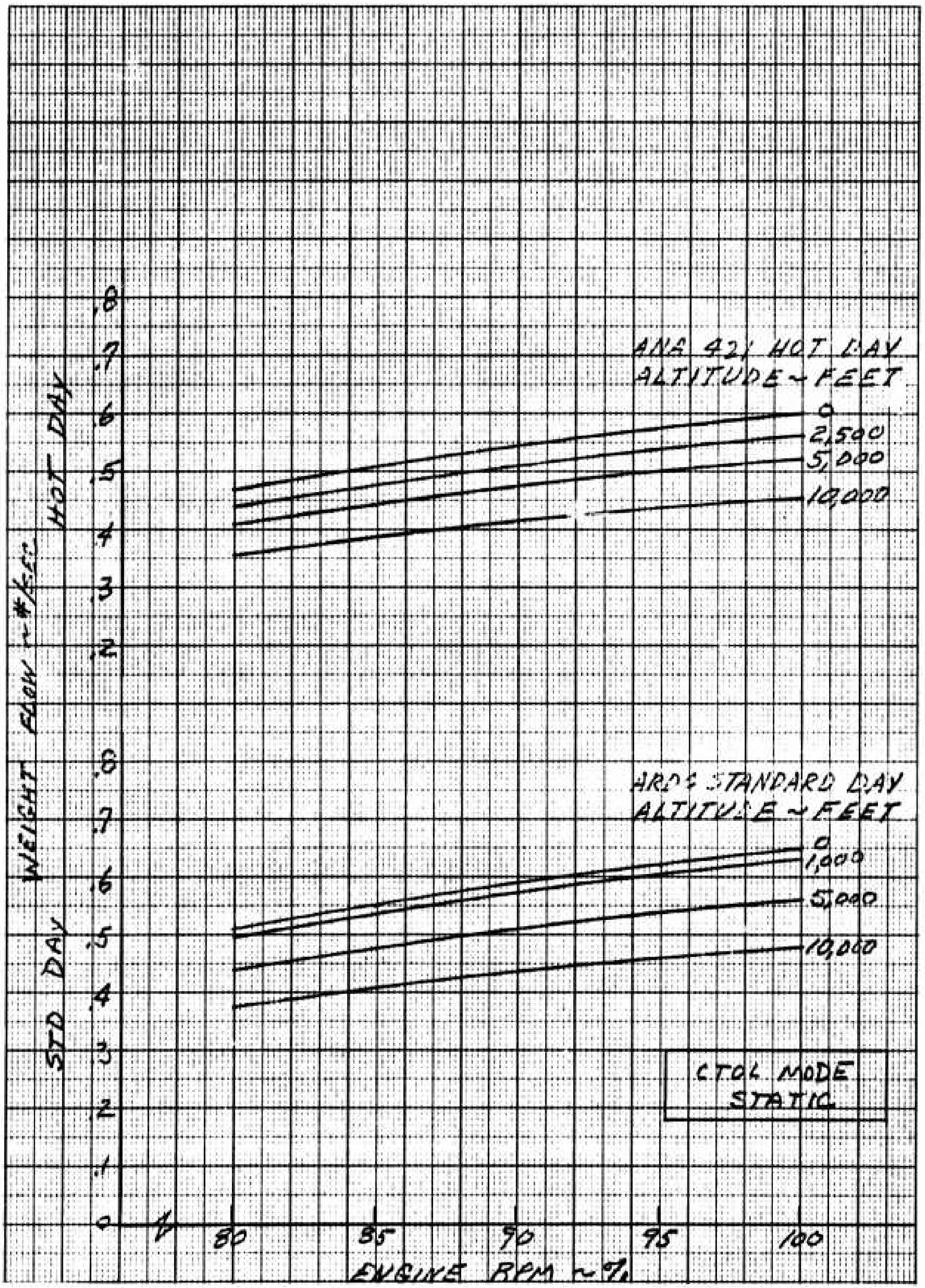

Figure 7.28 Cooling Air Weight Flow - Center Fuselage to Wing Fan Cavities Vs % RPM and Altitude - Conventional Mode, Standard and Hot Day

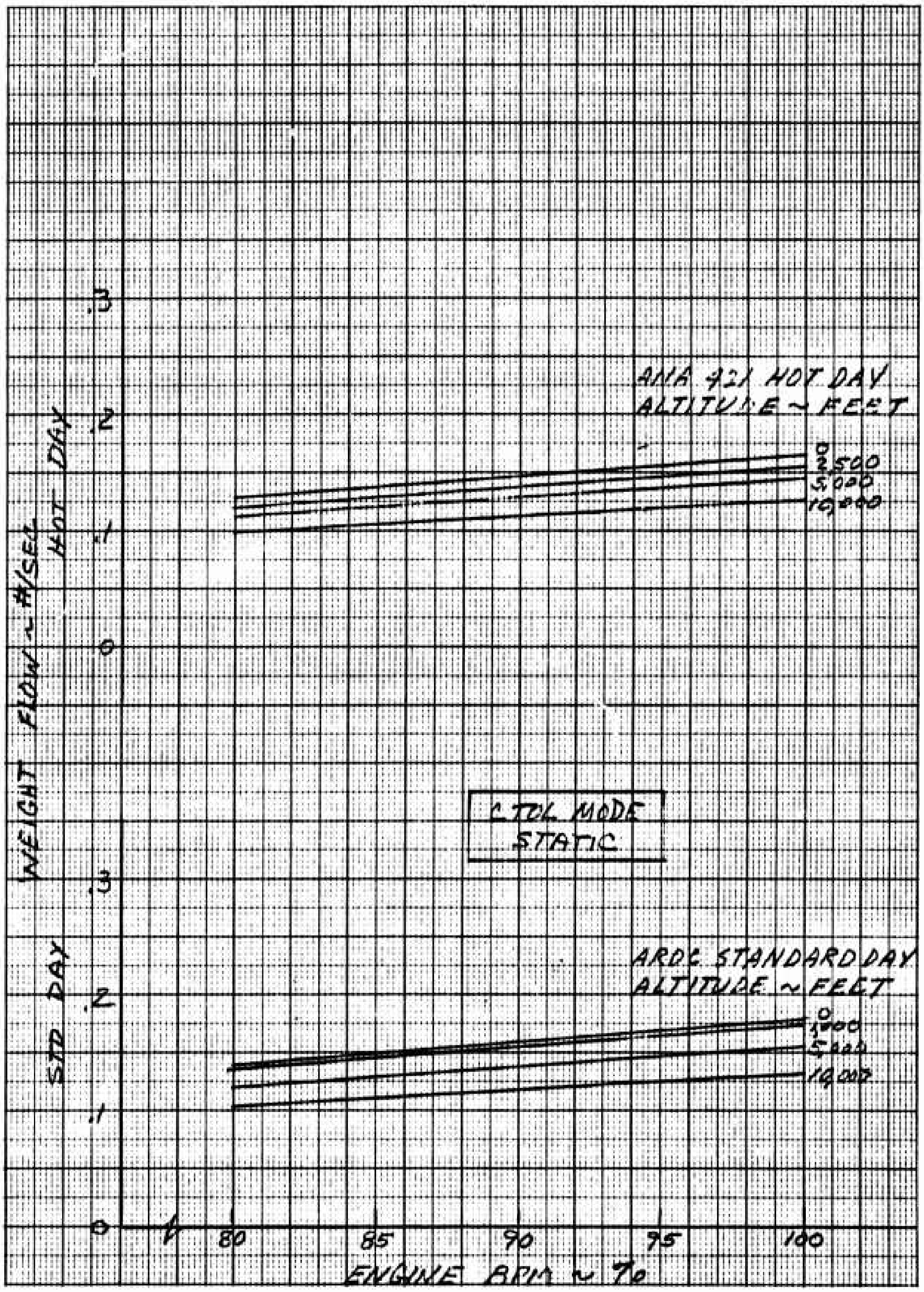

Figure 7.29 Cooling Air Weight Flow - Forward Fuselage to Nose Fan Cavity Vs % RPM and Altitude - Conventional Mode, Standard and Hot Day

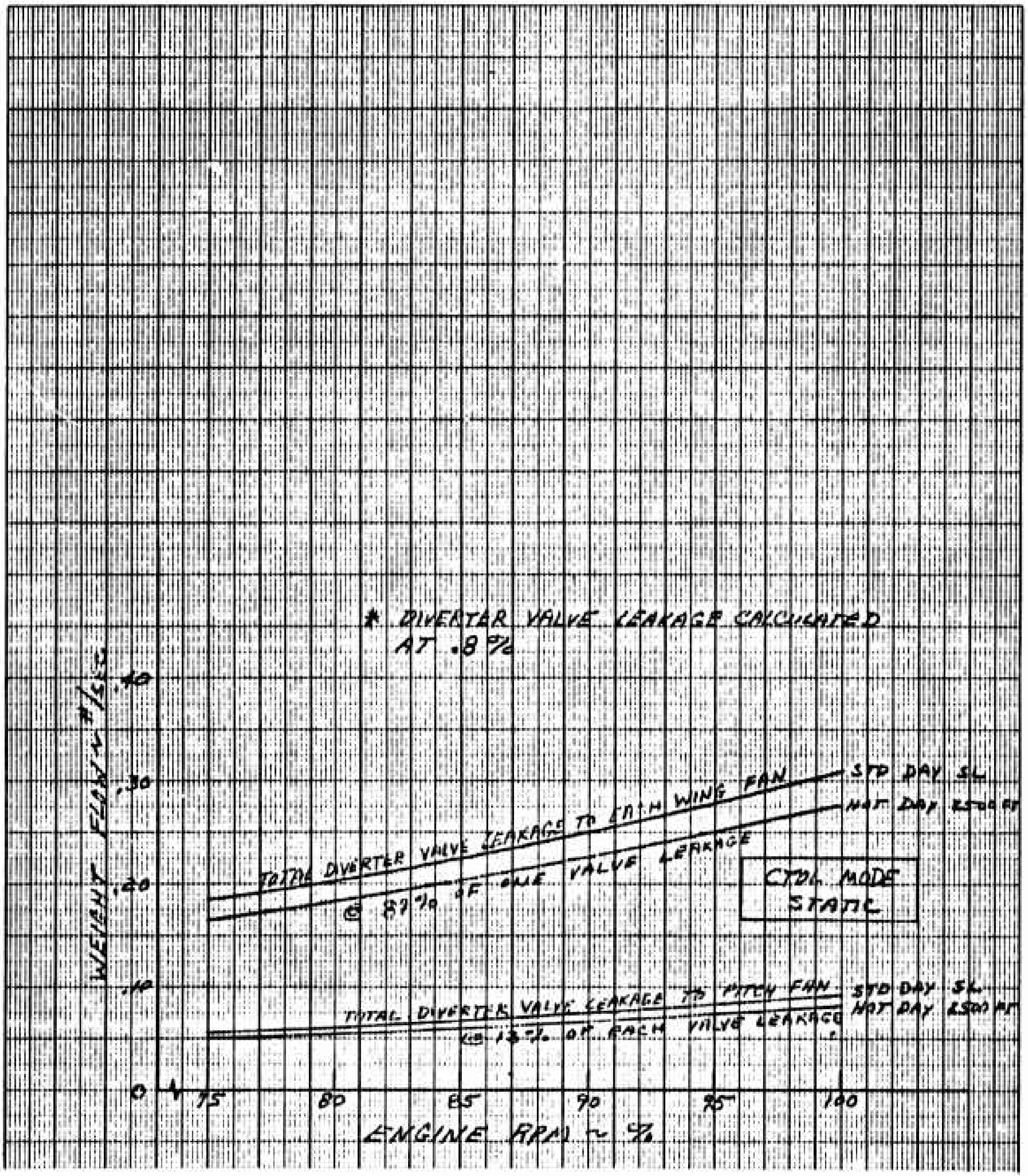

Figure 7.30 Diverter Valve Leakage to Wing and Nose Fan Cavities Vs % RPM - Conventional Mode, Standard and Hot Day

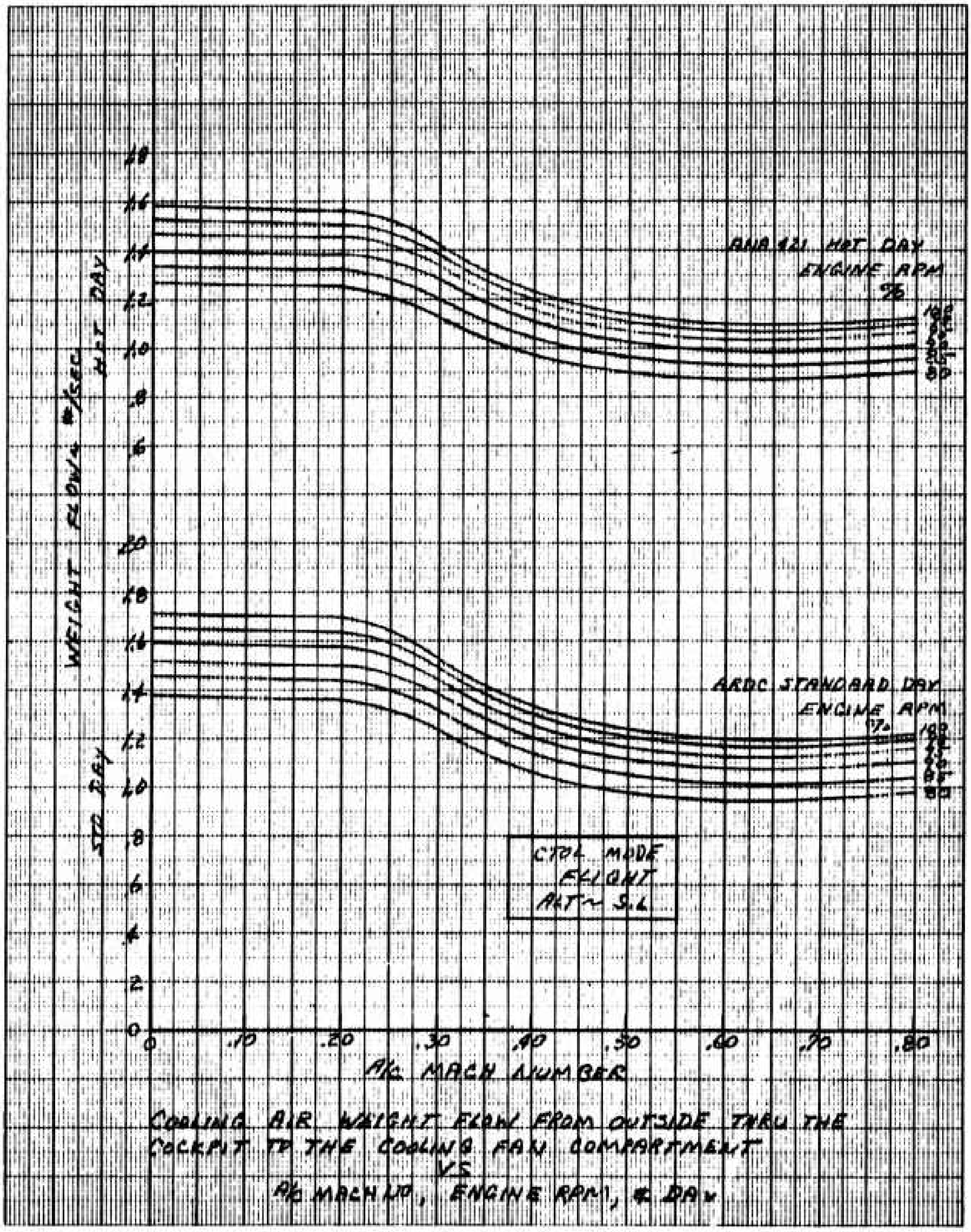

Figure 7.31 Cooling Air Weight Flow - Cockpit to Cooling Fan Compartment Vs Aircraft Mach No. and % RPM - Conventional Flight Mode, Standard and Hot Day, Sea Level

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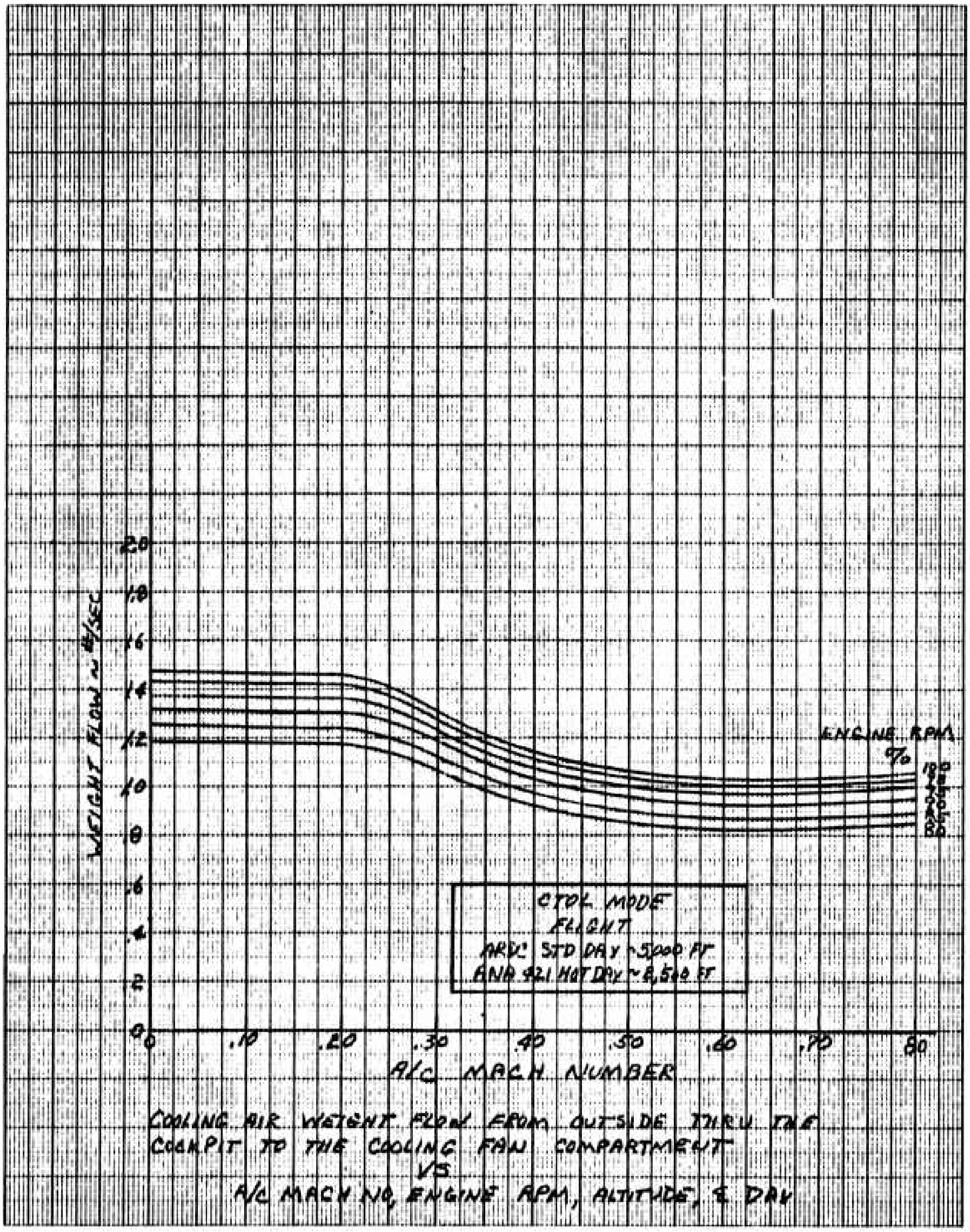

Figure 7.32 Cooling Air Weight Flow - Cockpit to Cooling Fan Compartment Vs Aircraft Mach No. and % RPM - Conventional Flight Mode, Standard Day, 5,000 Ft. and Hot Day 2,500 Ft.

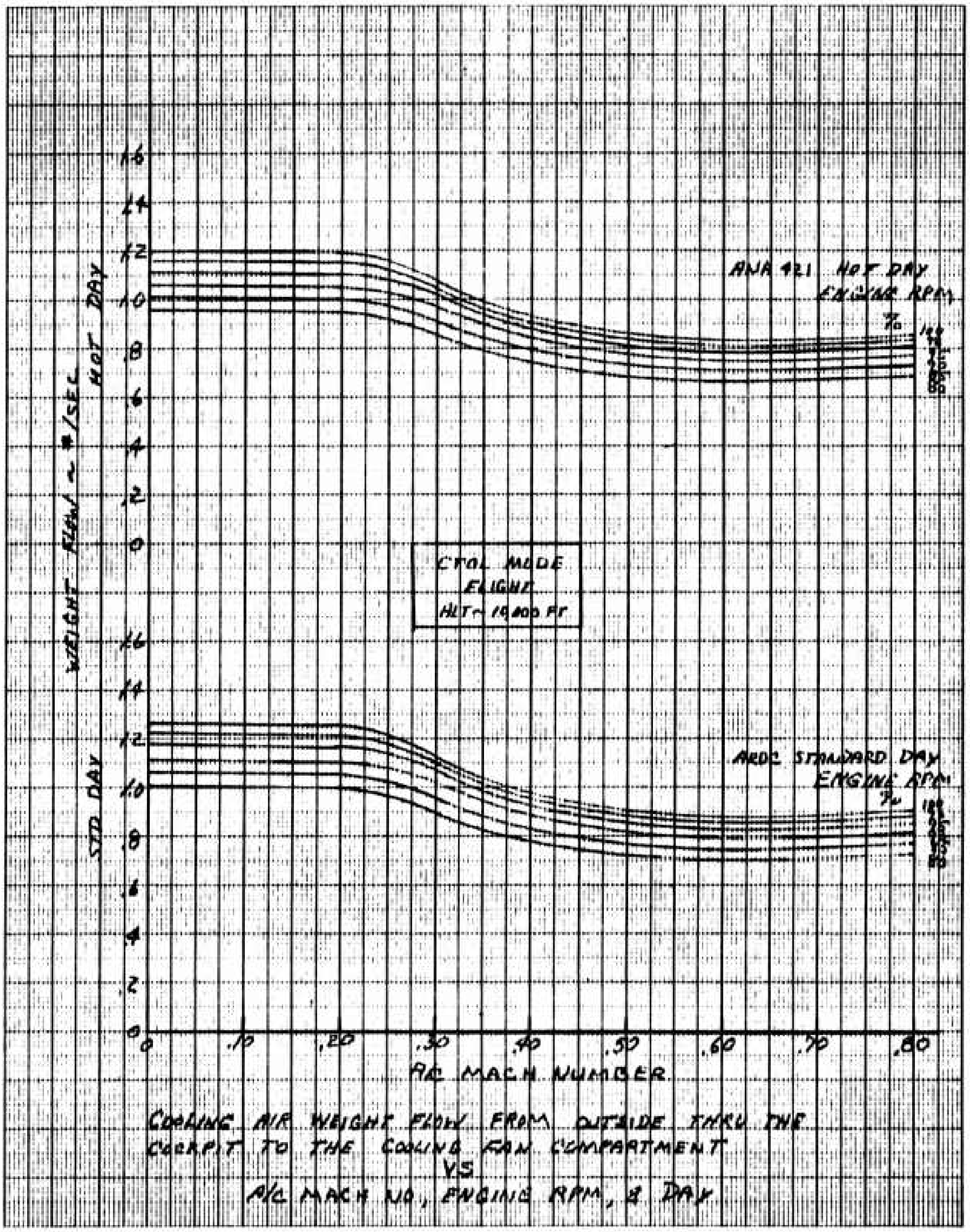

Figure 7.33 Cooling Air Weight Flow - Cockpit to Cooling Fan Compartment Vs Aircraft Mach No. and % RPM - Conventional Flight Mode, Standard and Hot Day, 10,000 Ft.

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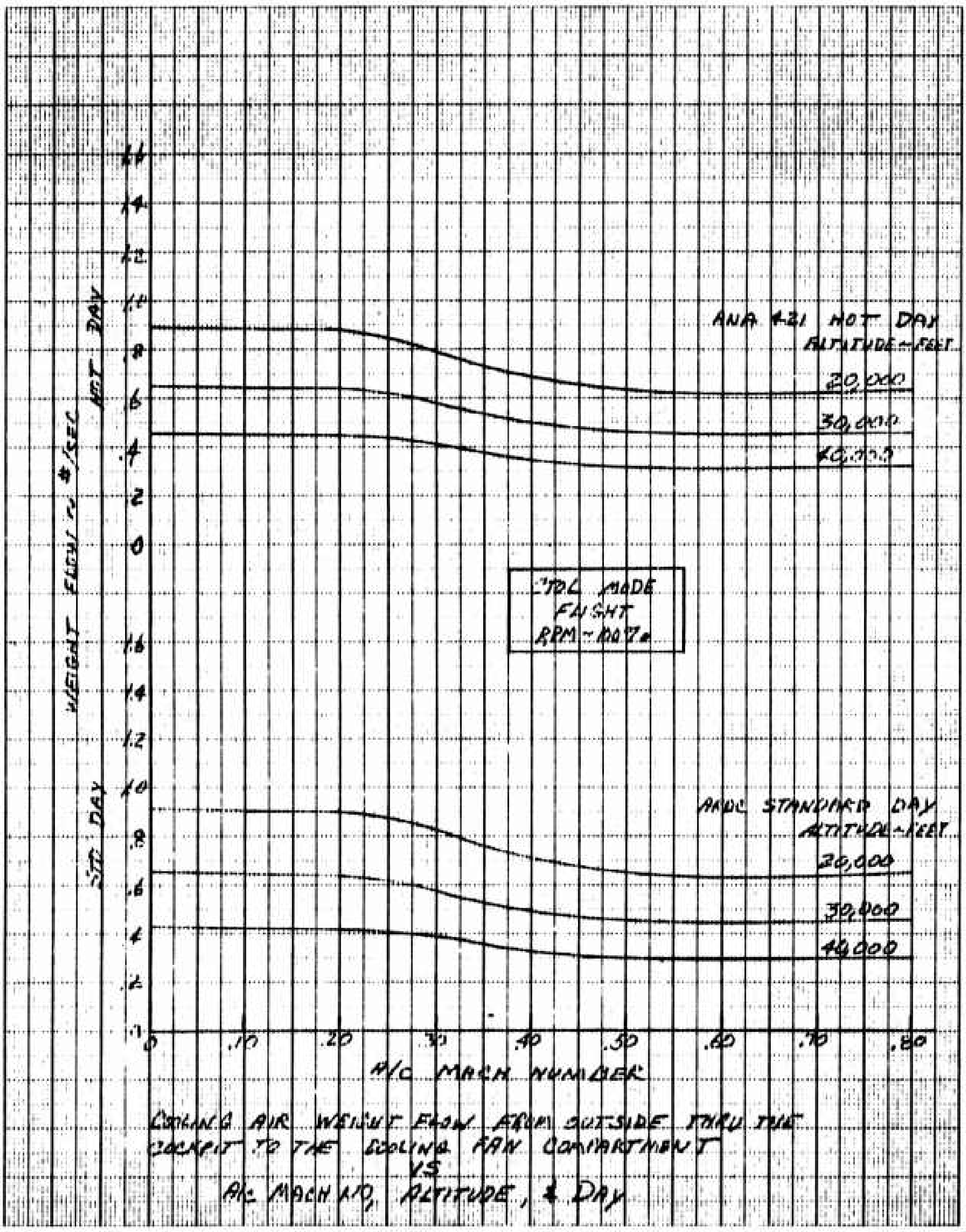

Figure 7.34 Cooling Air Weight Flow - Cockpit to Cooling Fan Compartment Vs Aircraft Mach No. and Altitude - Conventional Flight Mode, 100% RPM, Standard and Hot Day

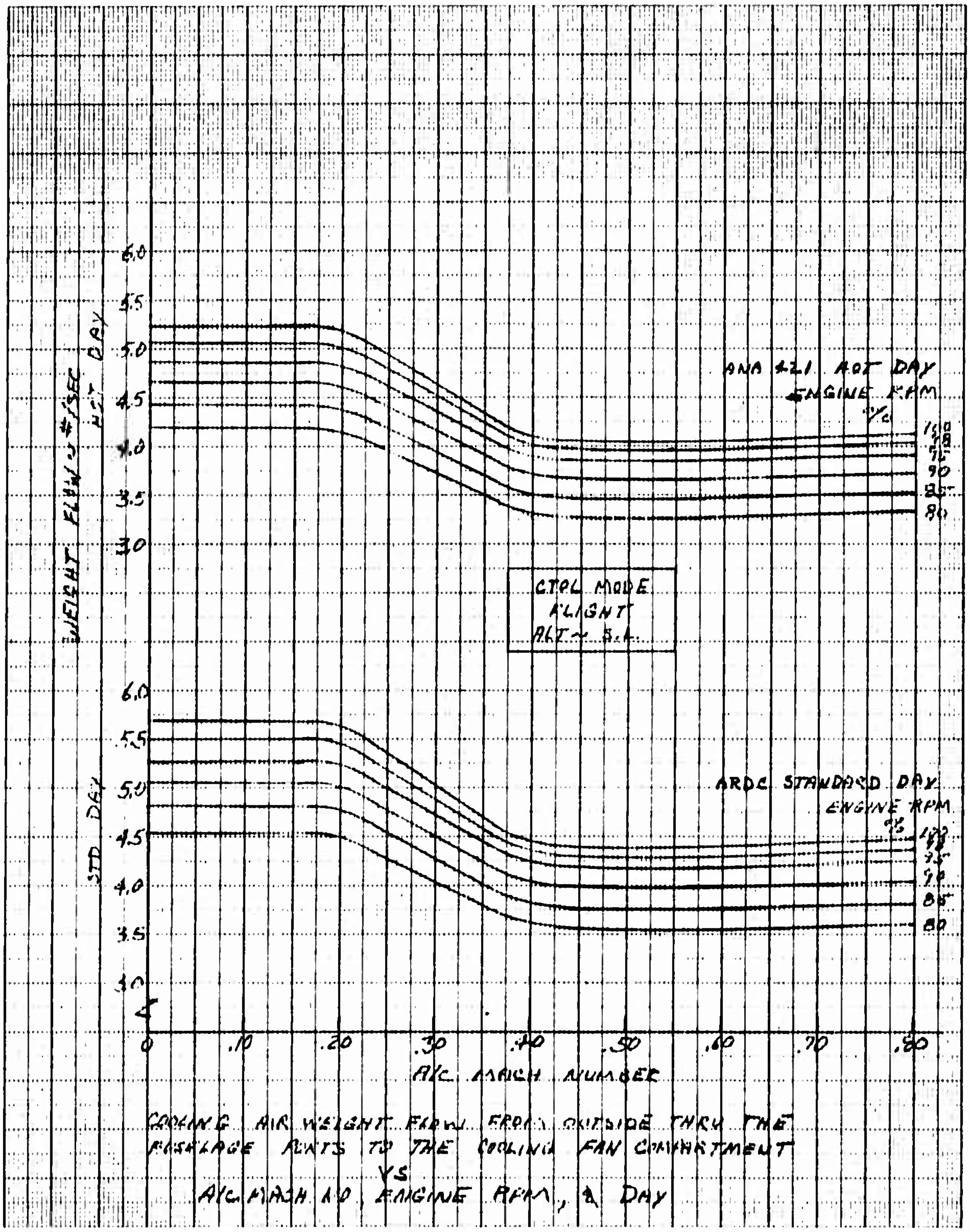

Figure 7.35 Cooling Air Weight Flow - Fuselage Ports to Cooling Fan Compartment Vs Aircraft Mach No. and % RPM - Conventional Flight Mode, Standard and Hot Day, Sea Level

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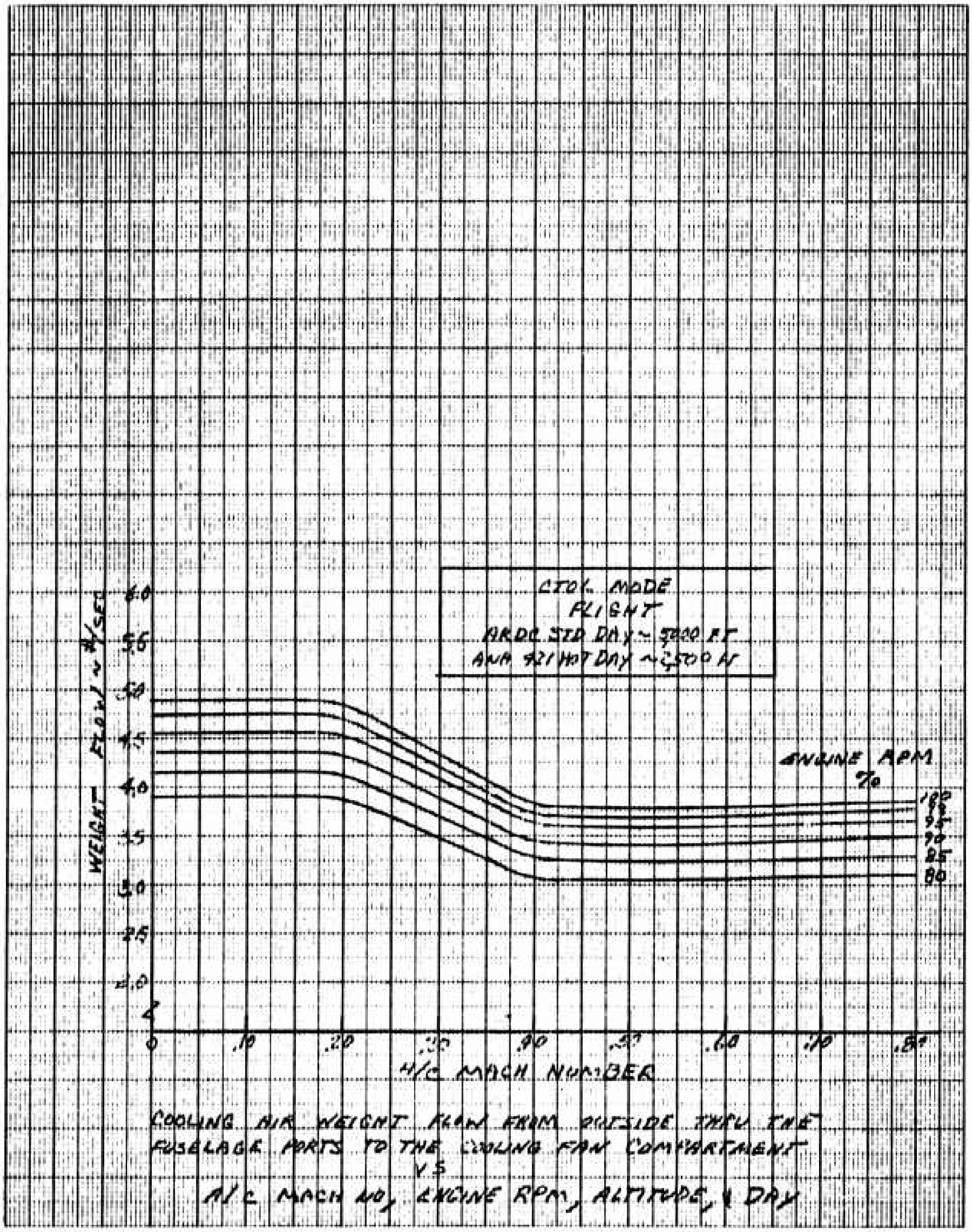

Figure 7.36 Cooling Air Weight Flow - Fuselage Ports to Cooling Fan Compartment Vs Aircraft Mach No. and % RPM - Conventional Flight Mode, Standard Day 5,000 Ft. and Hot Day 2,500 Ft.

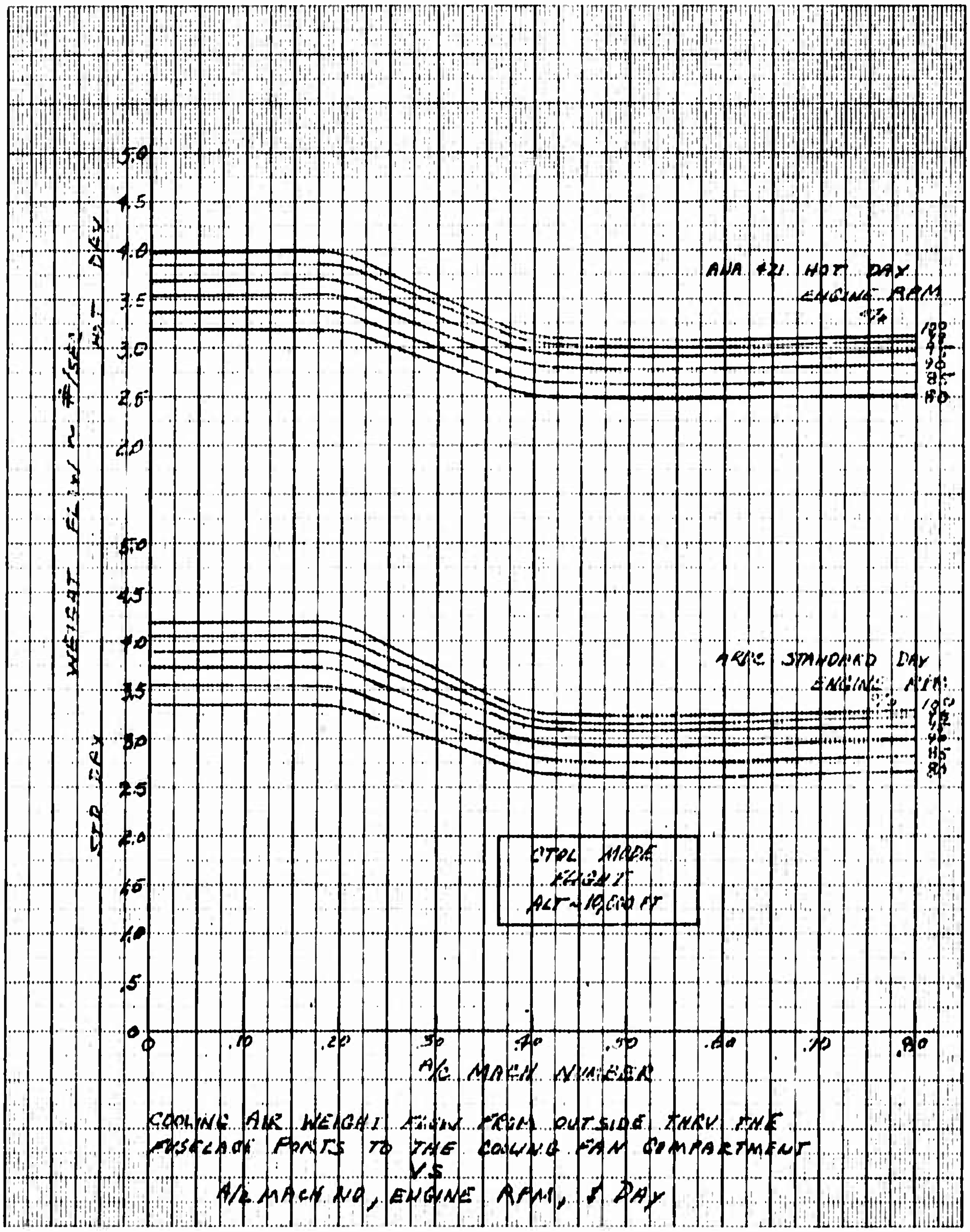

Figure 7.37 Cooling Air Weight Flow - Fuselage Ports to Cooling Fan Compartment Vs Aircraft Mach No. and % RPM - Conventional Flight Mode, Standard and Hot Day, 10,000 Ft.

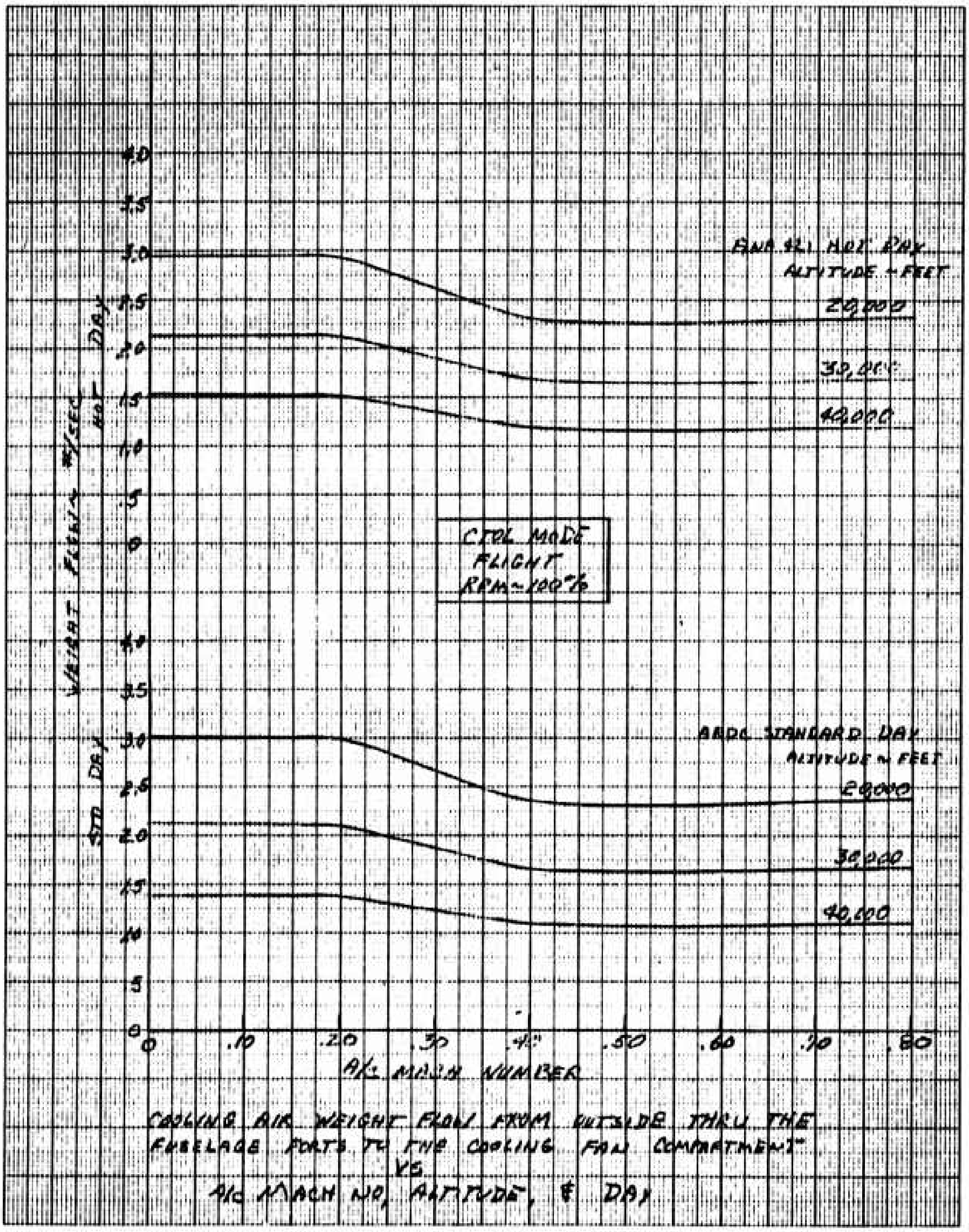

Figure 7.38 Cooling Air Weight Flow - Fuselage Ports to Cooling Fan Compartment Vs Aircraft Mach No. and Altitude - Conventional Flight Mode, 100% RPM, Standard and Hot Day

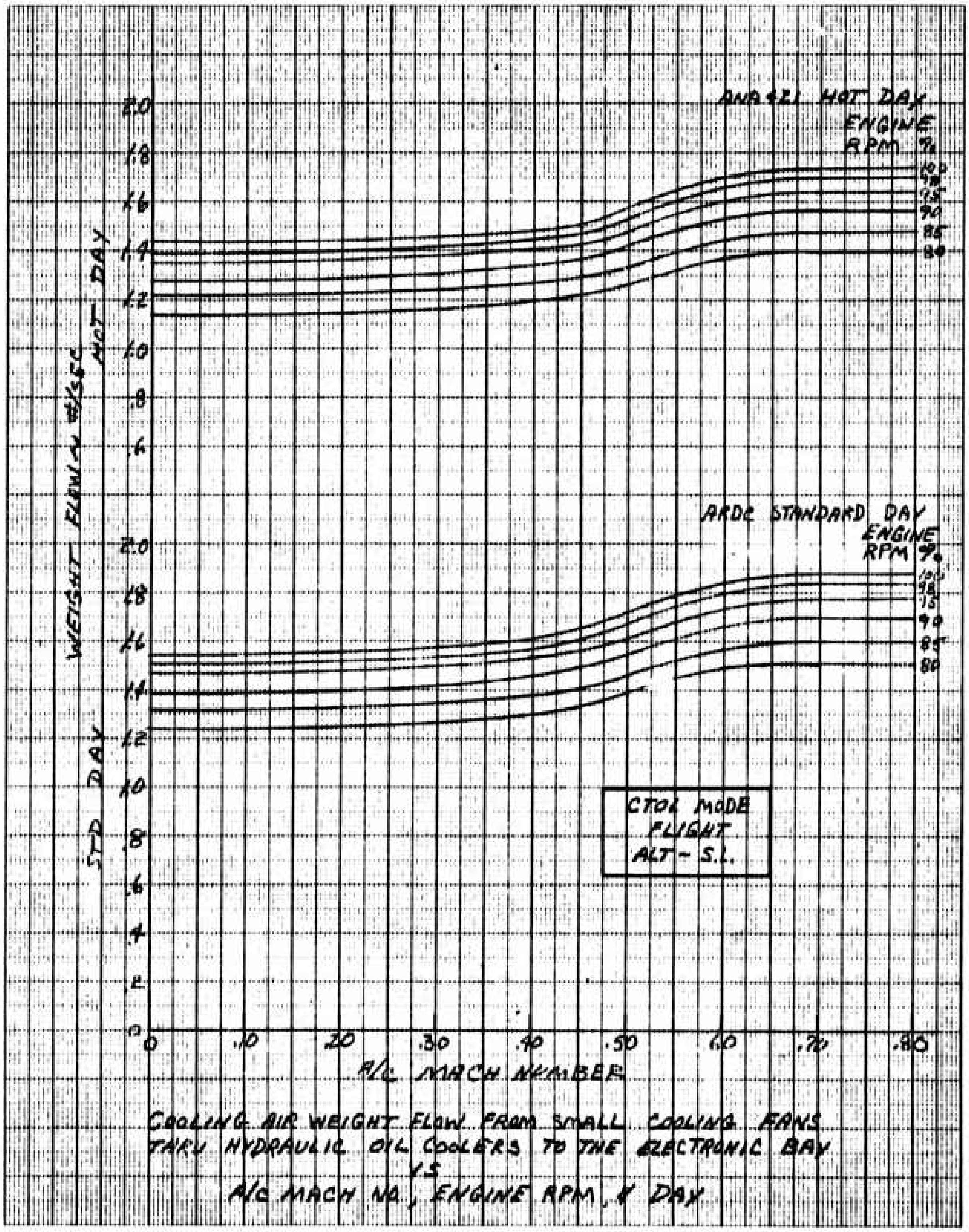

Figure 7.39 Cooling Air Weight Flow - Small Cooling Fans to Electronic Compartment Vs Aircraft Mach No. and % RPM - Conventional Flight Mode, Standard and Hot Day, Sea Level

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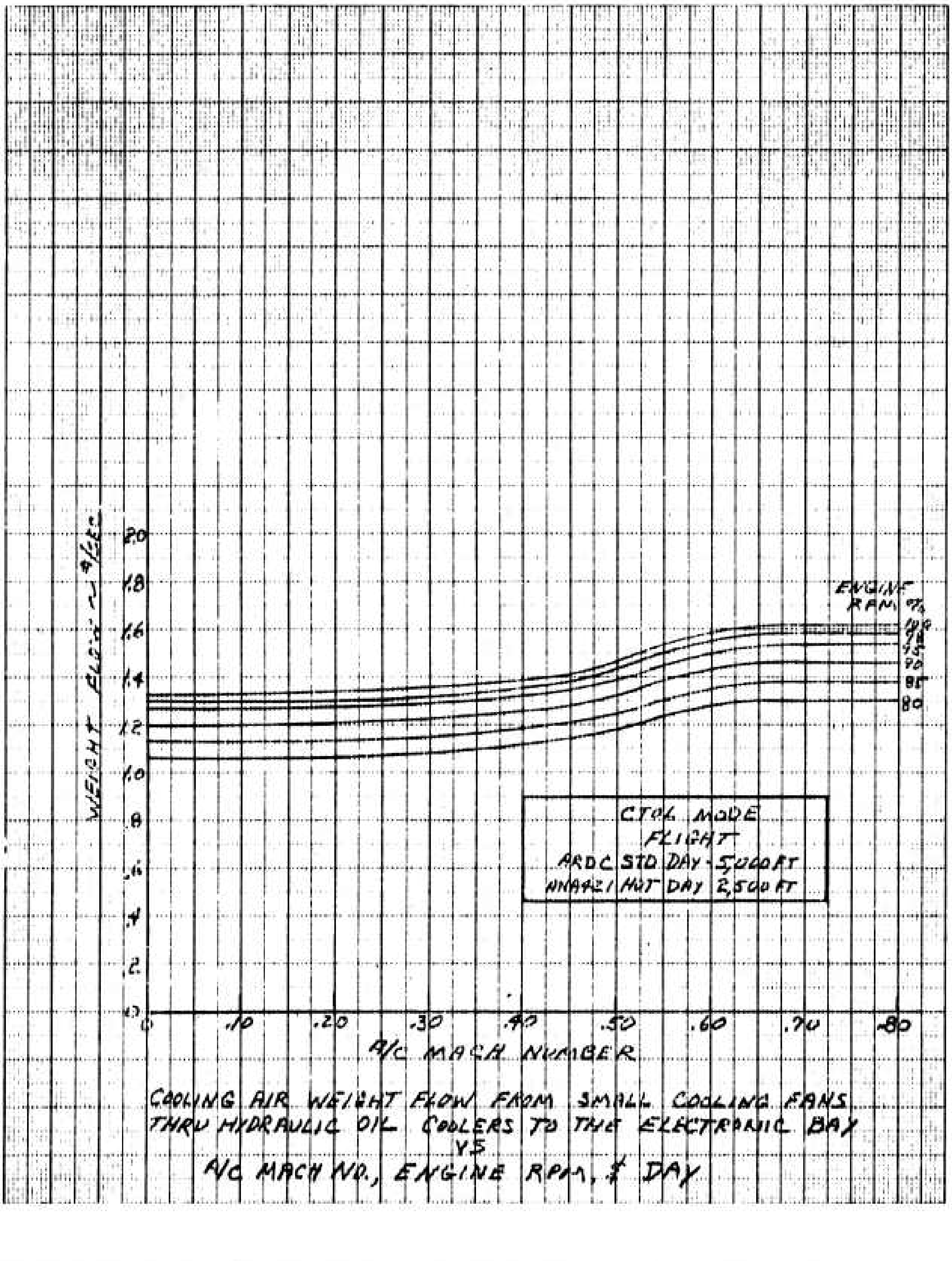

Figure 7.40 Cooling Air Weight Flow - Small Cooling Fans to Electronic Compartment Vs Aircraft Mach No. and % RPM - Conventional Flight Mode, Standard Day 5,000 Ft. and Hot Day 2,500 Ft.

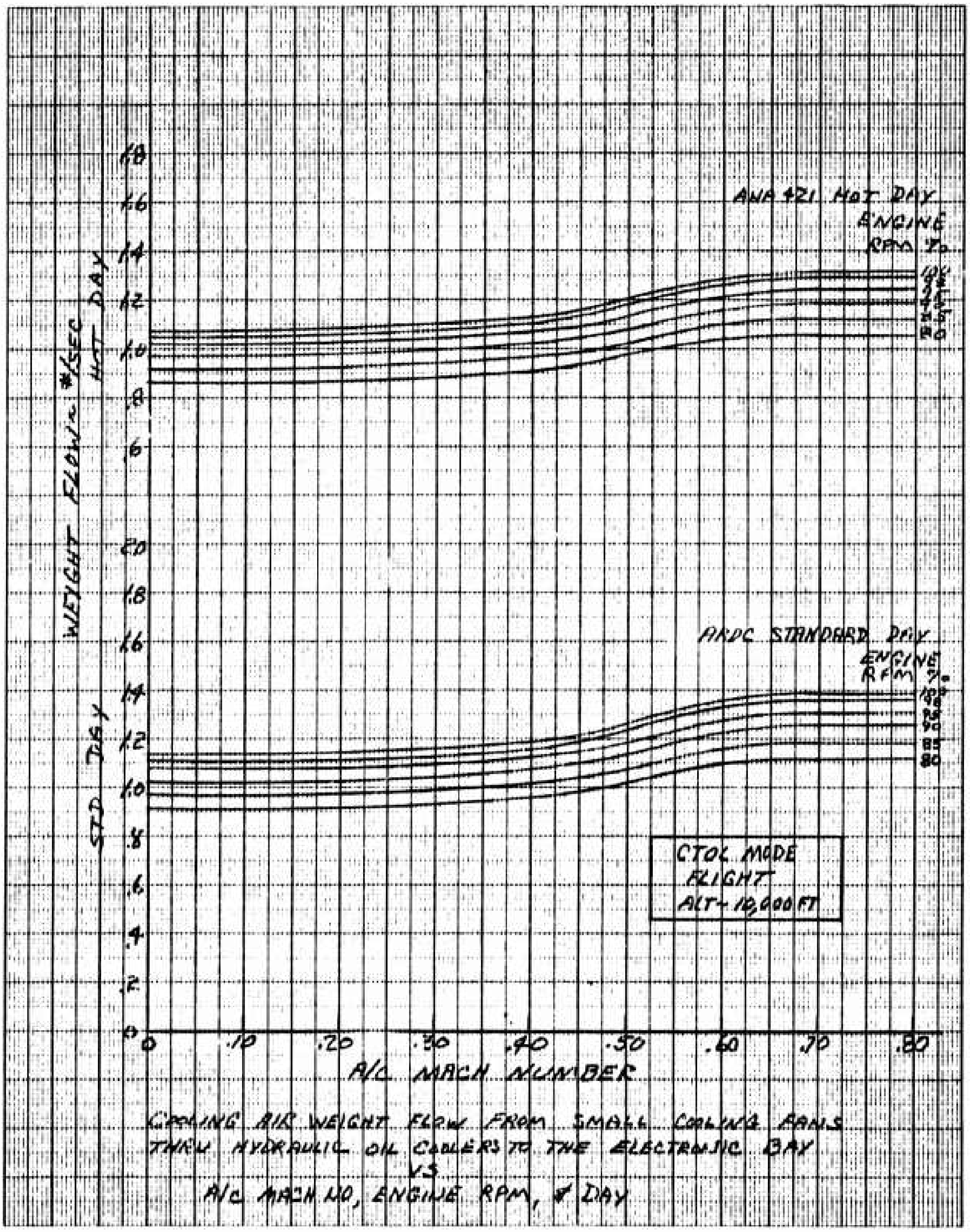

Figure 7.41 Cooling Air Weight Flow - Small Cooling Fans to Electronic Compartment Vs Aircraft Mach No. and % RPM - Conventional Flight Mode, Standard and Hot Day, 10,000 Ft.

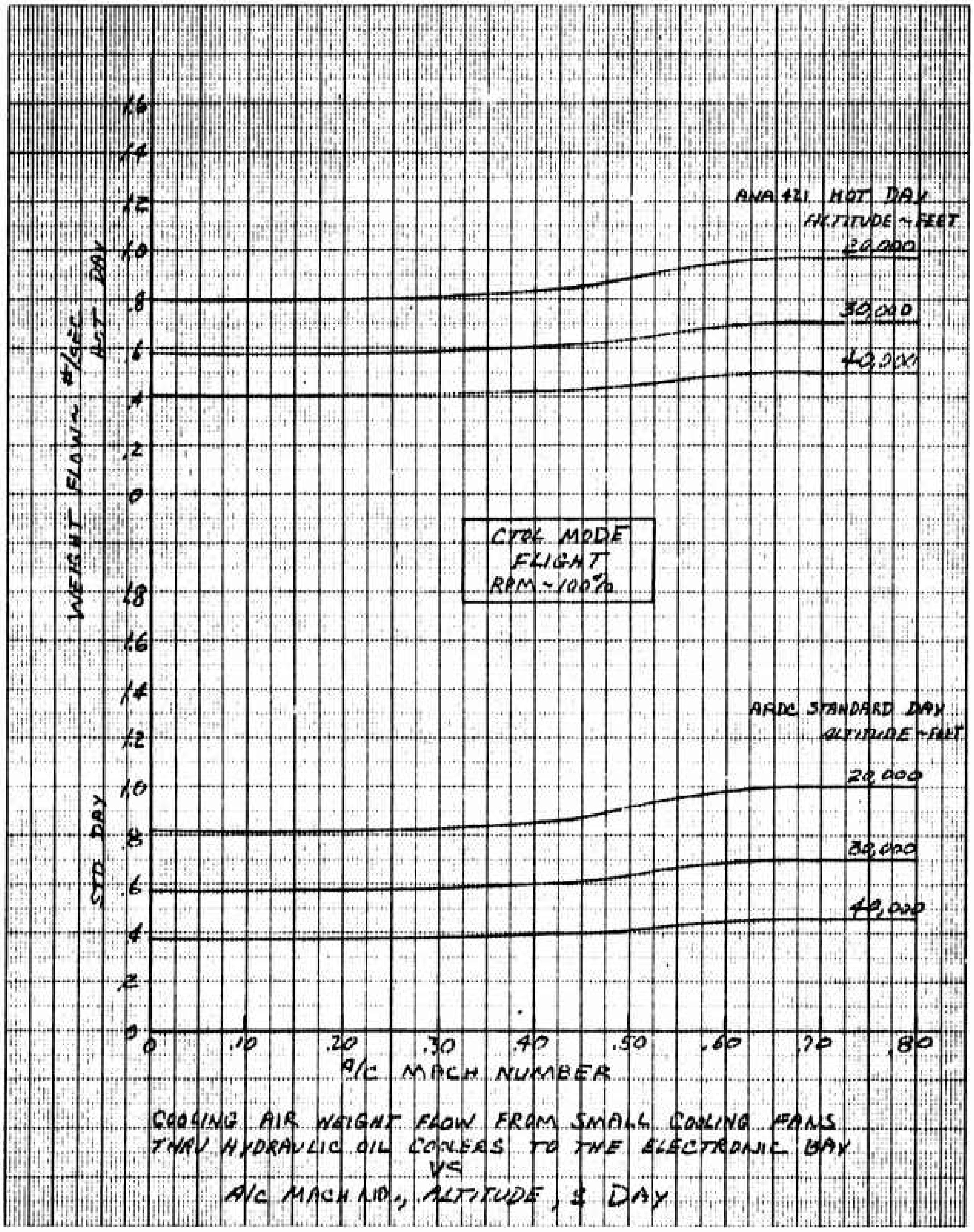

Figure 7.42 Cooling Air Weight Flow - Small Cooling Fans to Electronic Compartment Vs Aircraft Mach and Altitude - Conventional Flight Mode, 100% RPM, Standard and Hot Day

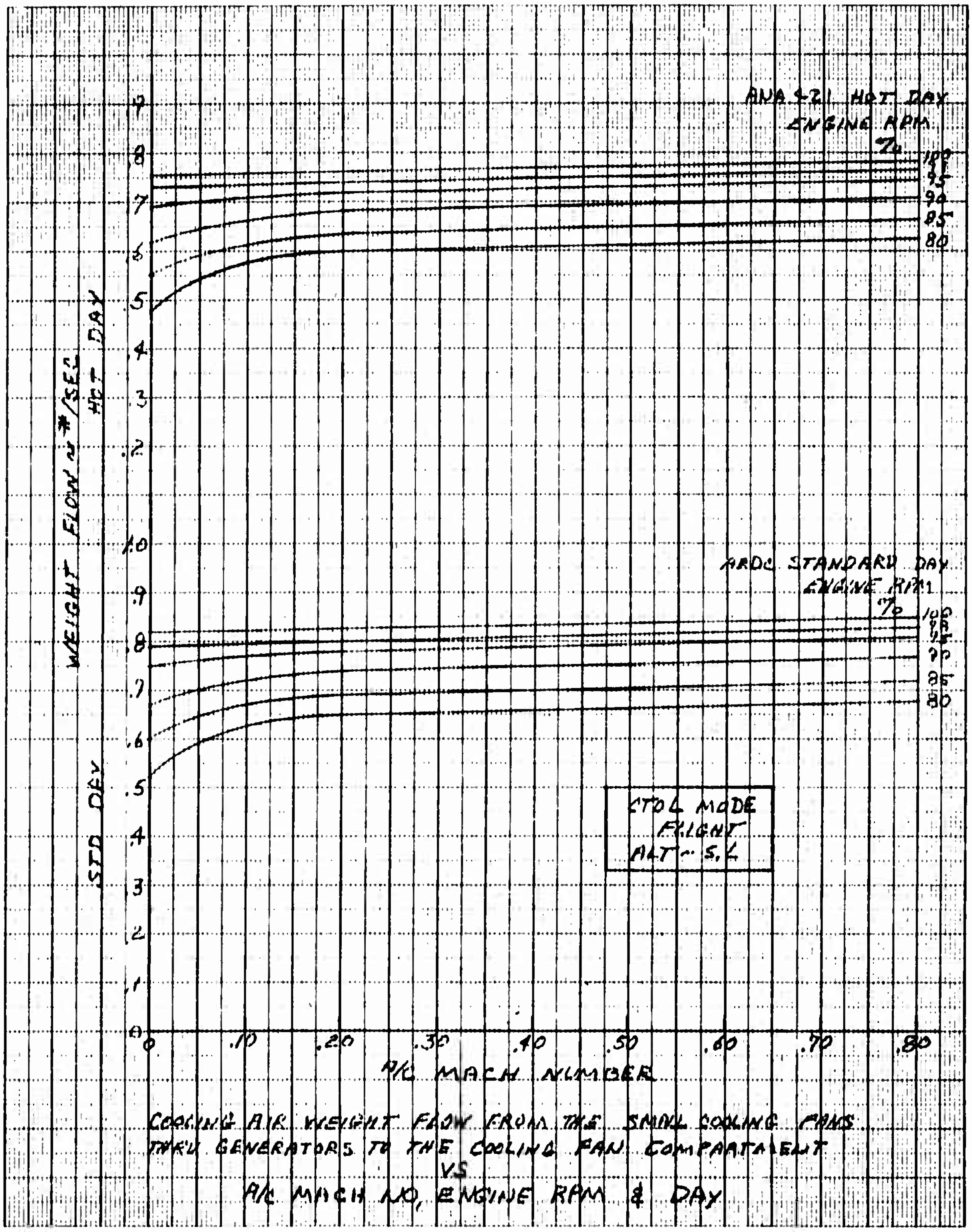

Figure 7.43 Cooling Air Weight Flow - Small Cooling Fans to Generators Vs Aircraft Mach No. and % RPM - Conventional Flight Mode, Standard and Hot Day, Sea Level

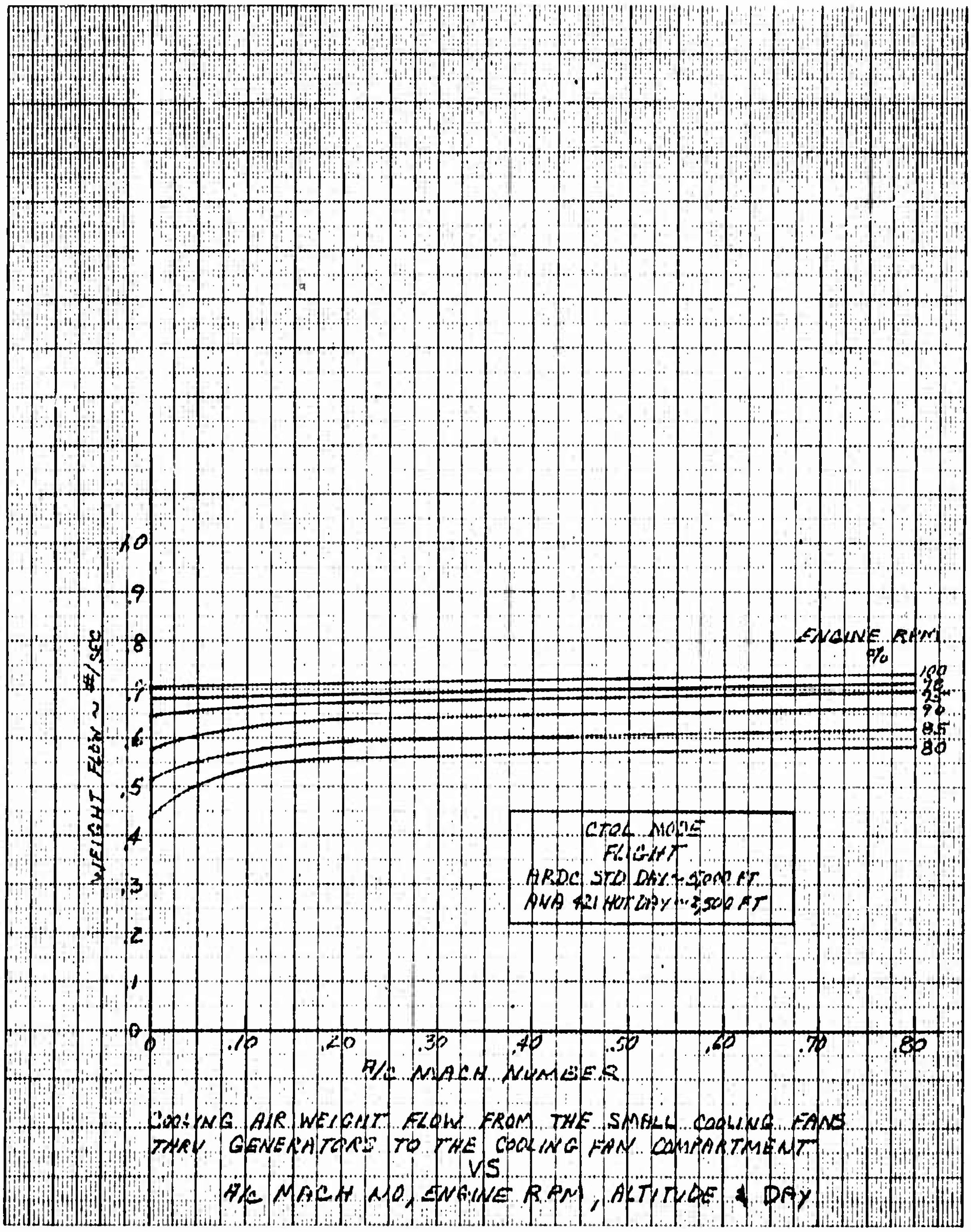

Figure 7.44 Cooling Air Weight Flow - Small Cooling Fans to Generators Vs Aircraft Mach No. and % RPM - Conventional Flight Mode, Standard Day 5,000 Ft. and Hot Day 2,500 Ft.

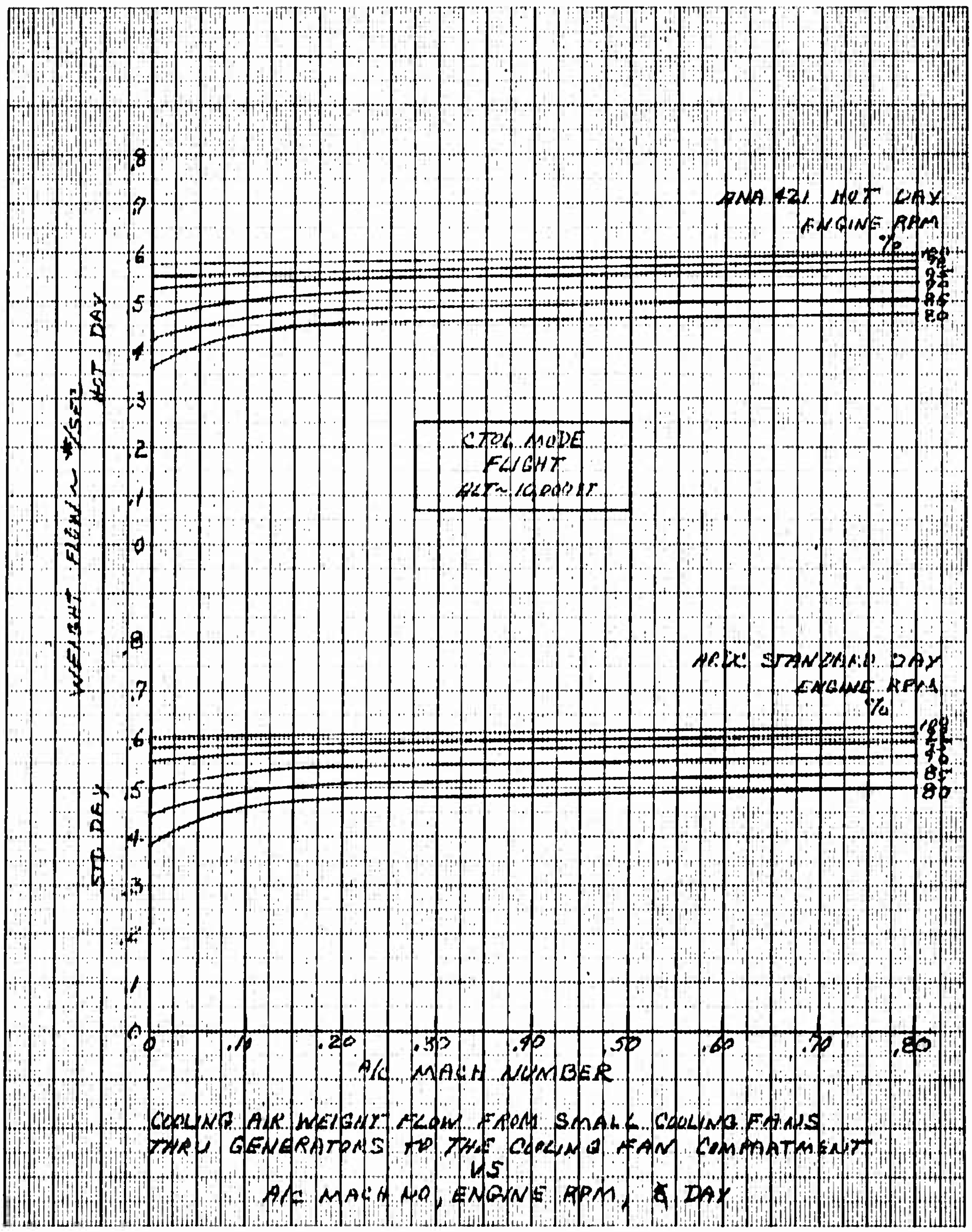

Figure 7.45 Cooling Air Weight Flow - Small Cooling Fans to Generators Vs Aircraft Mach No. and % RPM - Conventional Flight Mode, Standard and Hot Day, 10,000 Ft.

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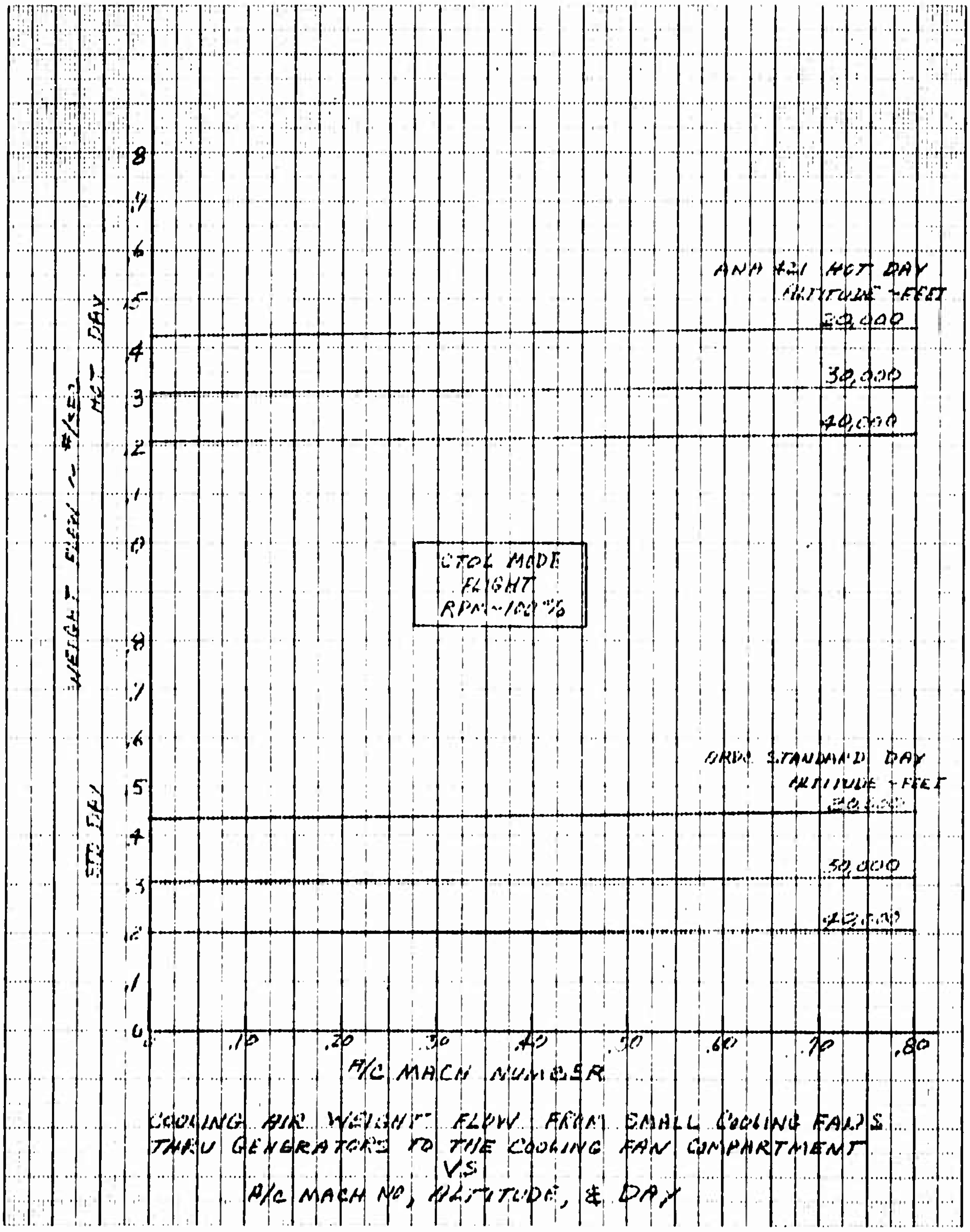

Figure 7.46 Cooling Air Weight Flow - Small Cooling Fans to Generators Vs Aircraft Mach No. and Altitude - Conventional Flight Mode, 100% RPM, Standard and Hot Day

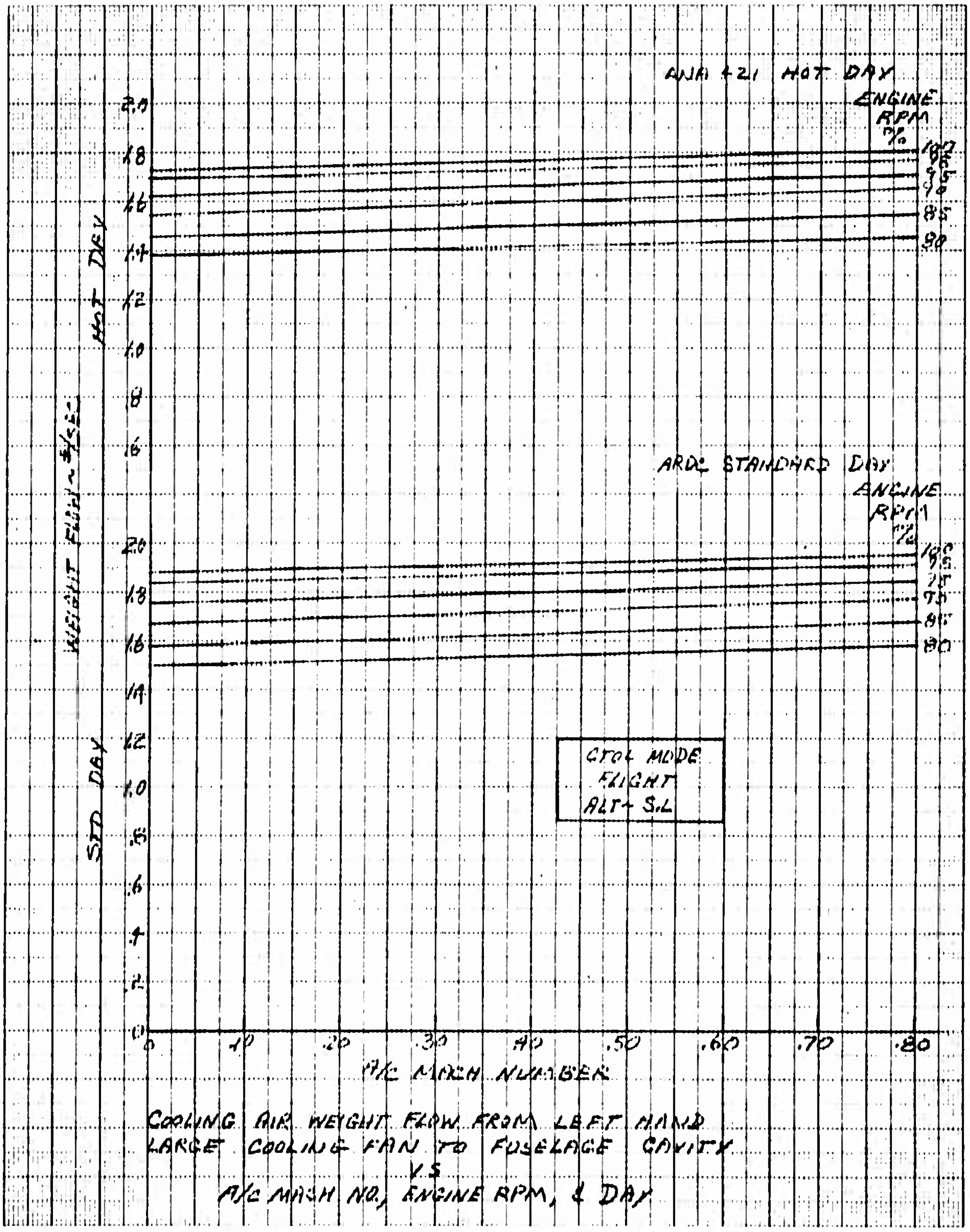

Figure 7.47 Cooling Air Weight Flow - L.H. Large Cooling Fan to Center Fuselage Vs Aircraft Mach No. and % RPM - Conventional Flight Mode, Standard and Hot Day, Sea Level

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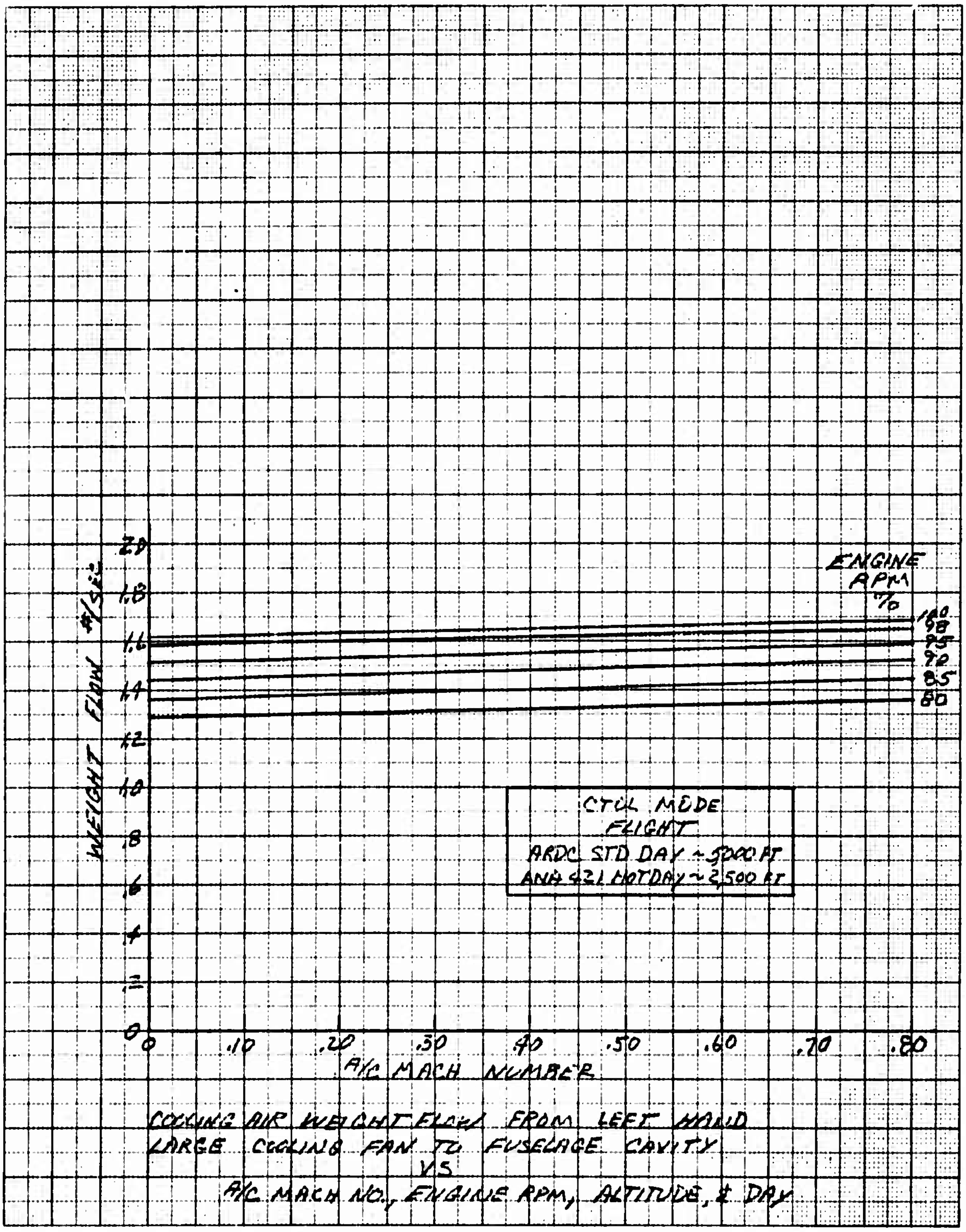

Figure 7.48 Cooling Air Weight Flow - L.H. Large Cooling Fan to Center Fuselage Vs Aircraft Mach No. and % RPM - Conventional Flight Mode, Standard Day 5,000 Ft. and Hot Day 2,500 Ft.

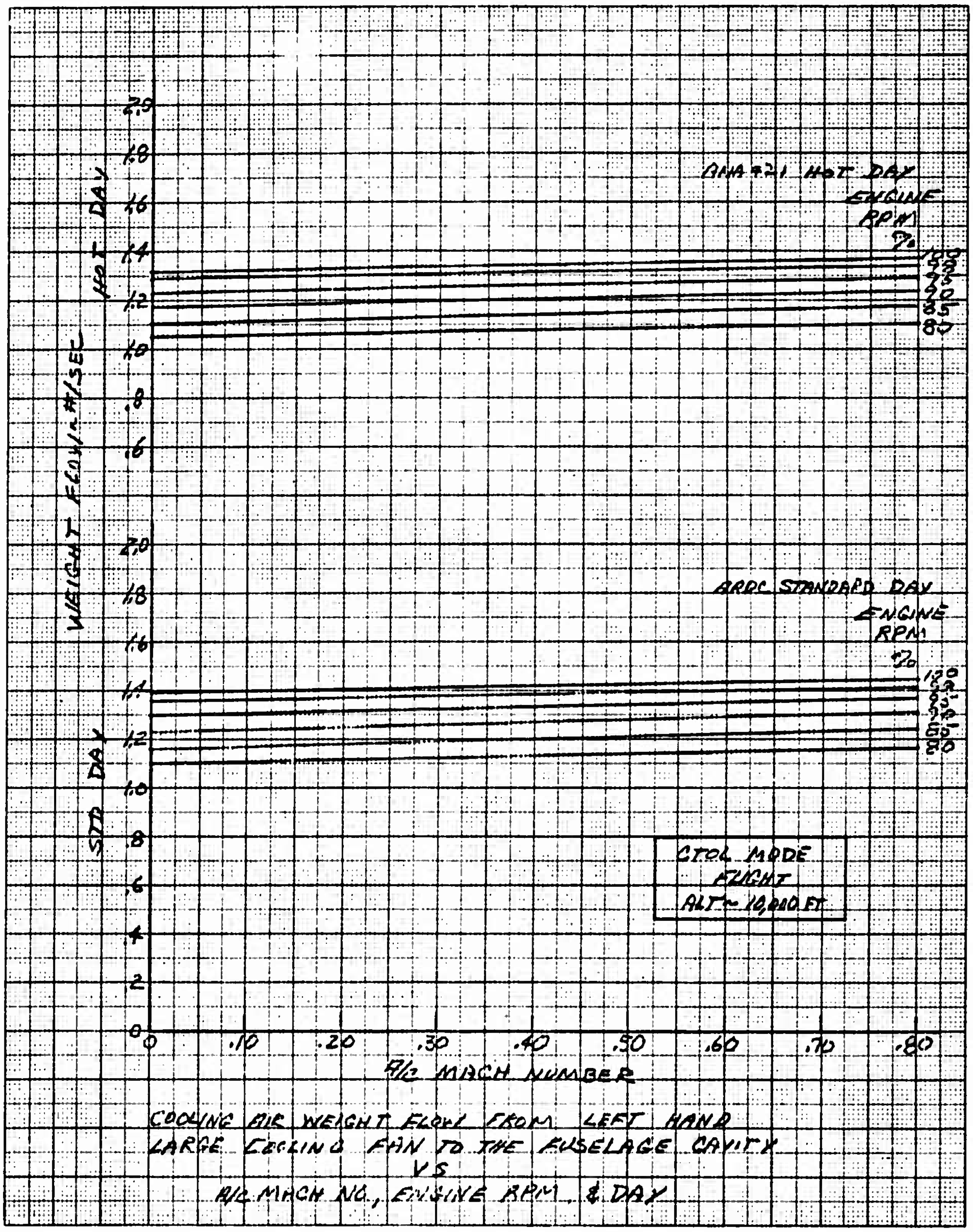

Figure 7.49 Cooling Air Weight Flow - L. H. Large Cooling Fan to Center Fuselage Vs Aircraft Mach No. and % RPM - Conventional Flight Mode, Standard and Hot Day, 10,000 Ft.

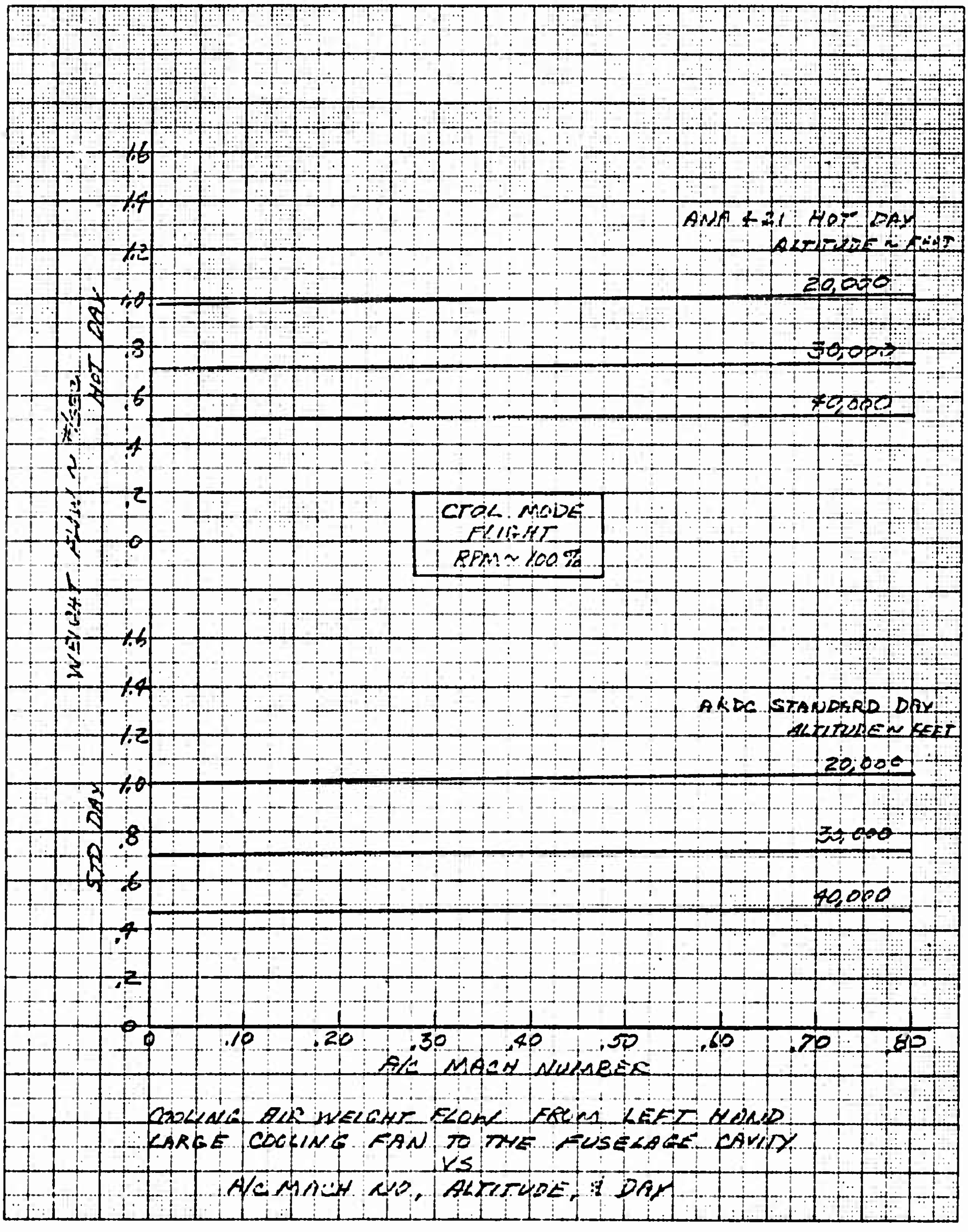

Figure 7.50 Cooling Air Weight Flow - L. H. Large Cooling Fan to Center Fuselage Vs Aircraft Mach No. and Altitude - Conventional Flight Mode, 100% RPM, Standard and Hot Day

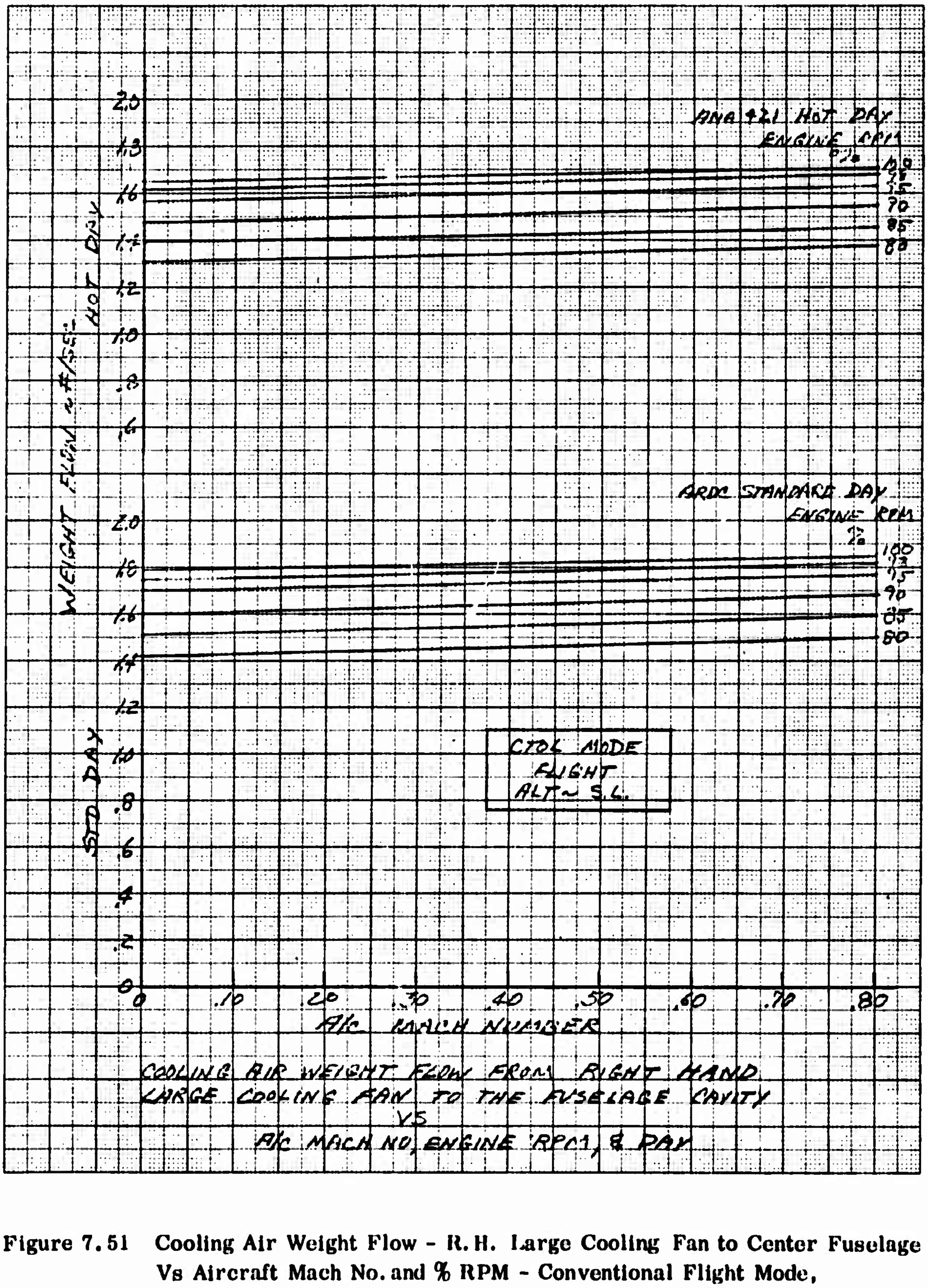

Figure 7.51 Cooling Air Weight Flow - R.H. Large Cooling Fan to Center Fuselage Vs Aircraft Mach No. and % RPM - Conventional Flight Mode, Standard and Hot Day, Sea Level

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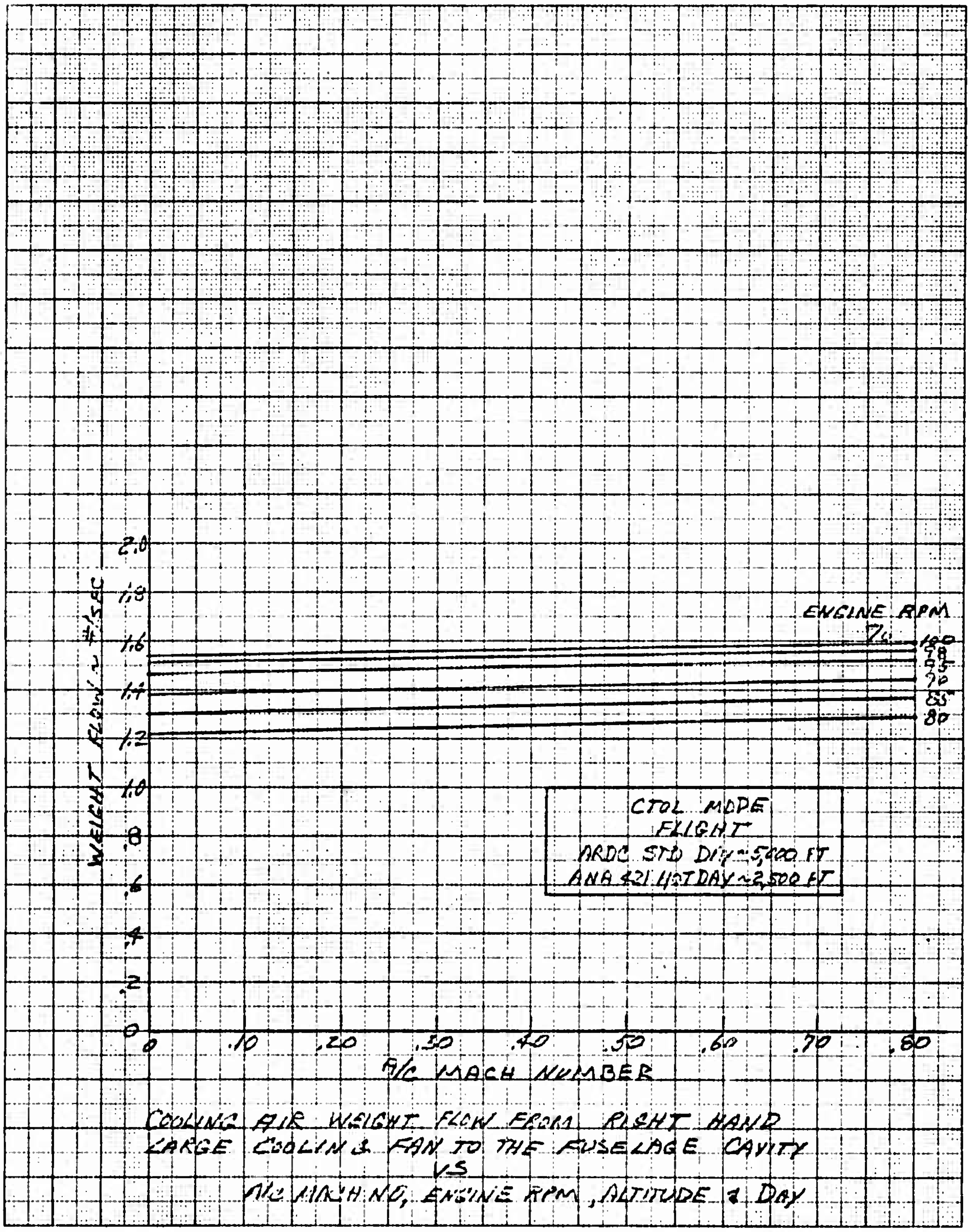

Figure 7.52 Cooling Air Weight Flow - R.H. Large Cooling Fan To Center Fuselage Vs Aircraft Mach No. and % RPM - Conventional Flight Mode, Standard Day 5,000 Ft. and Hot Day 2,500 Ft.

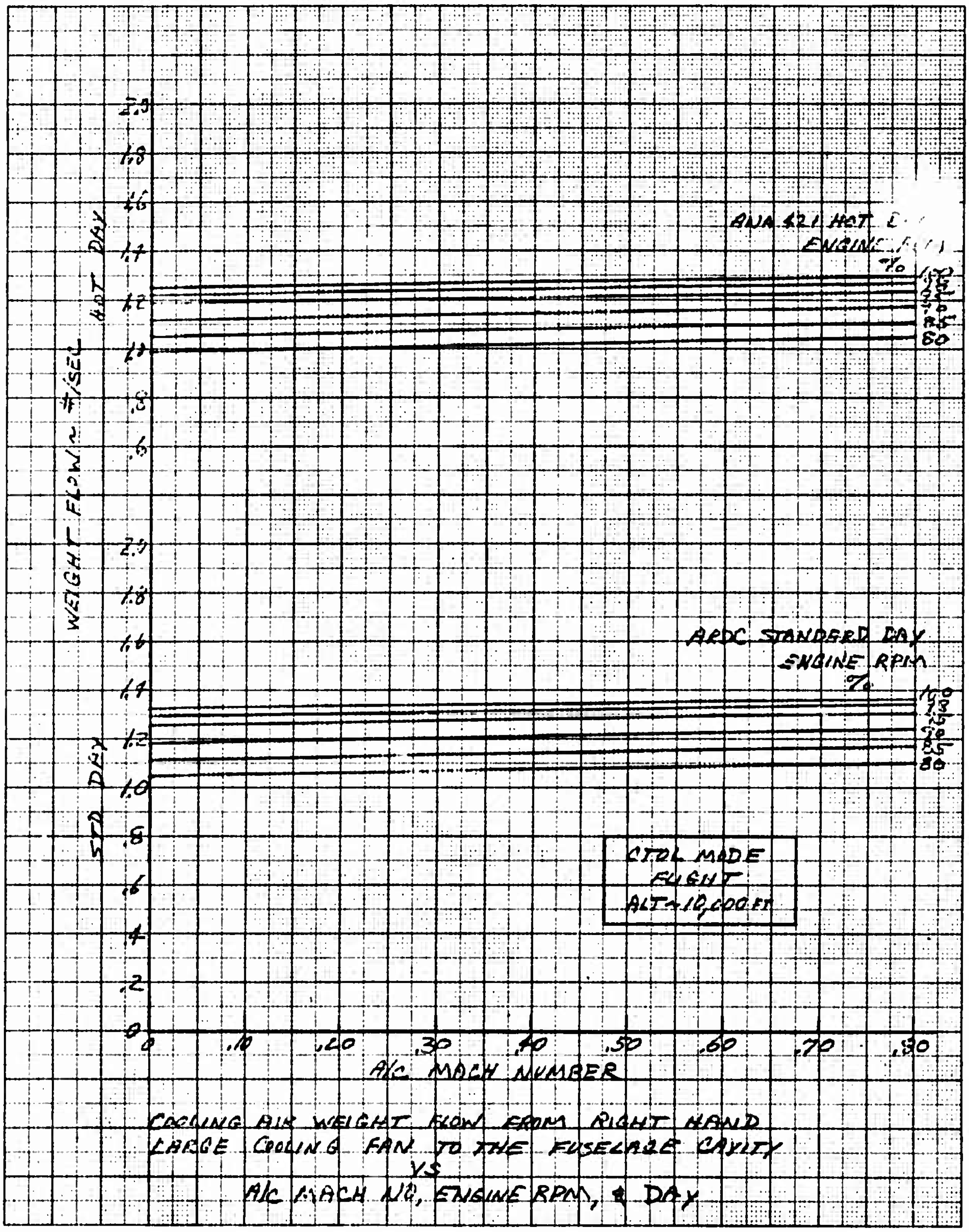

Figure 7.53 Cooling Air Weight Flow - R.H. Large Cooling Fan to Center Fuselage Vs Aircraft Mach No. and % RPM - Conventional Flight Mode, Standard and Hot Day, 10,000 Ft.

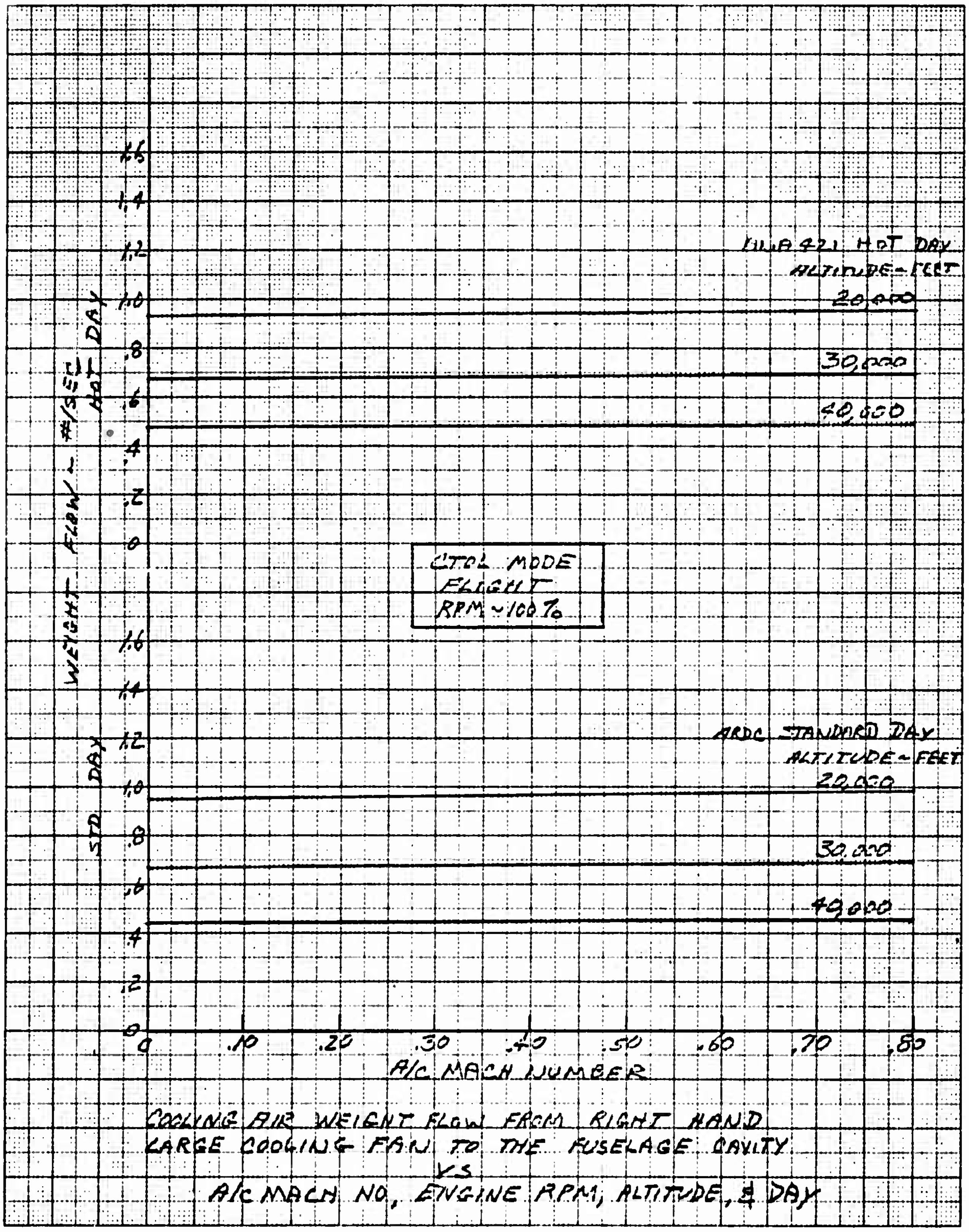

Figure 7.54 Cooling Air Weight Flow - R.H. Large Cooling Fan to Center Fuselage Vs Aircraft Mach No. and Altitude - Conventional Flight Mode, 100% RPM, Standard and Hot Day

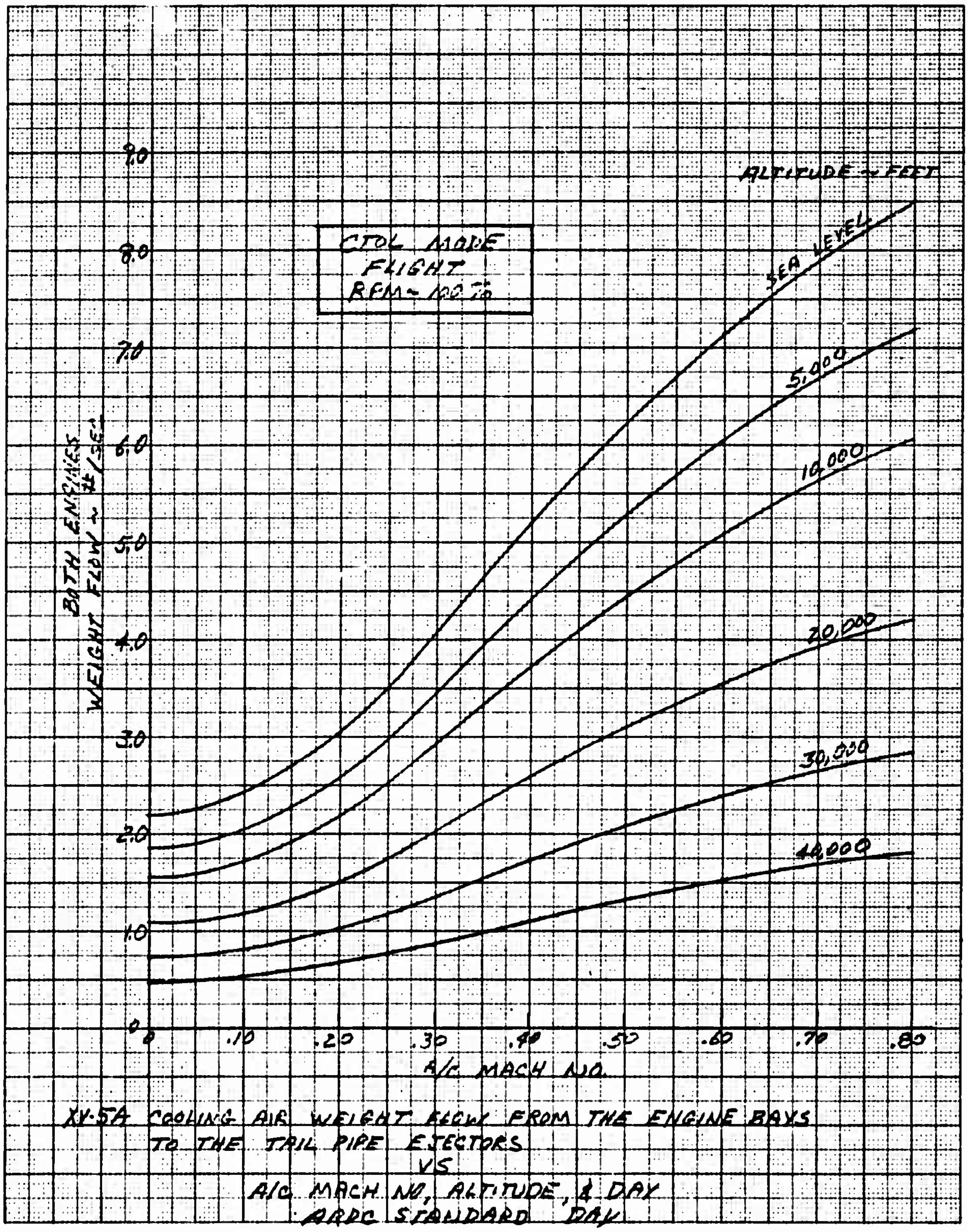

Figure 7.55 Cooling Air Weight Flow - Engine Bays to Tailpipe Ejectors Vs Aircraft Mach No. and Altitude - Conventional Flight Mode, 100% RPM, Standard Day

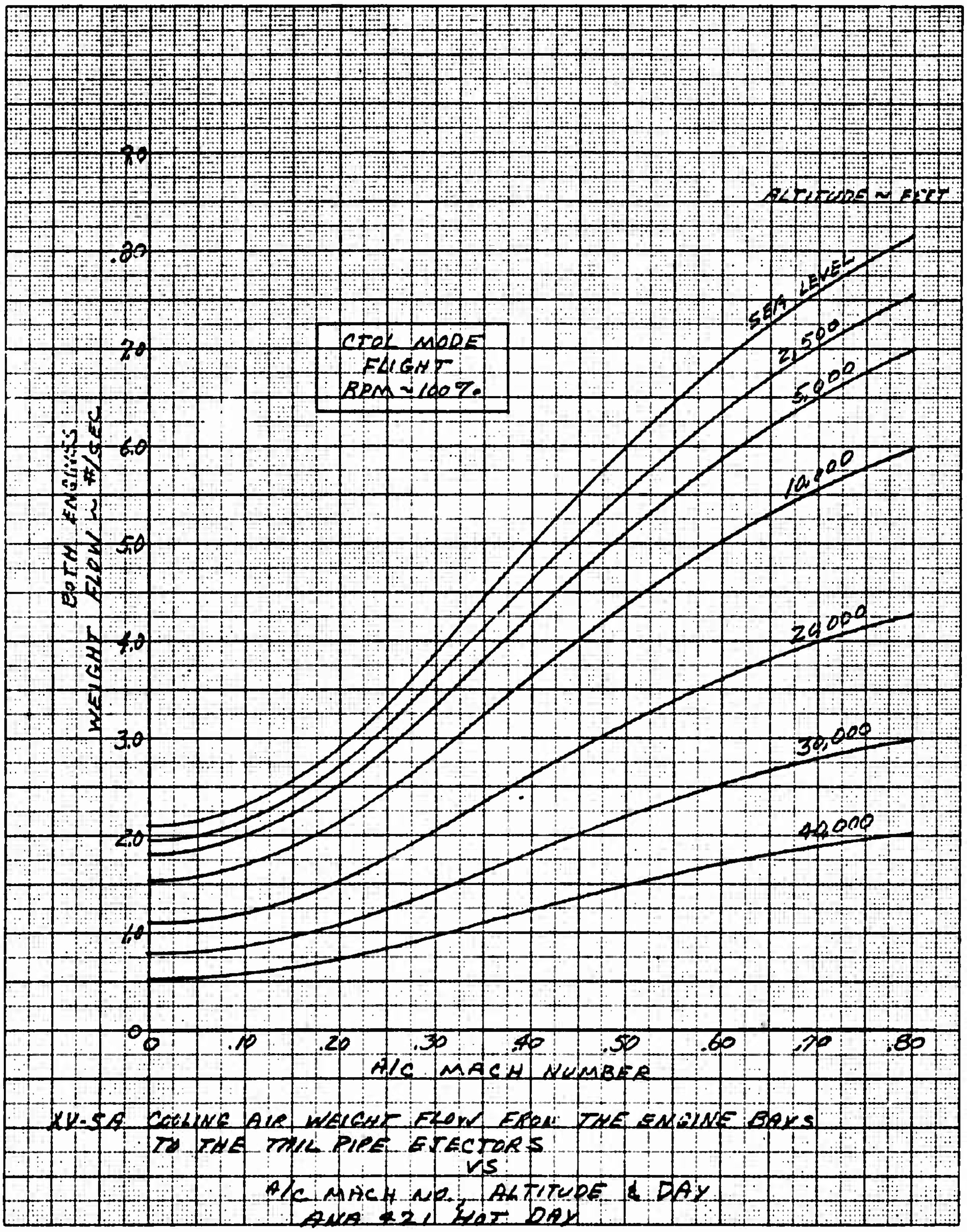

Figure 7.56 Cooling Air Weight Flow - Engine Bays to Tailpipe Ejectors Vs Aircraft Mach No. and Altitude - Conventional Flight Mode, 100% RPM, Hot Day

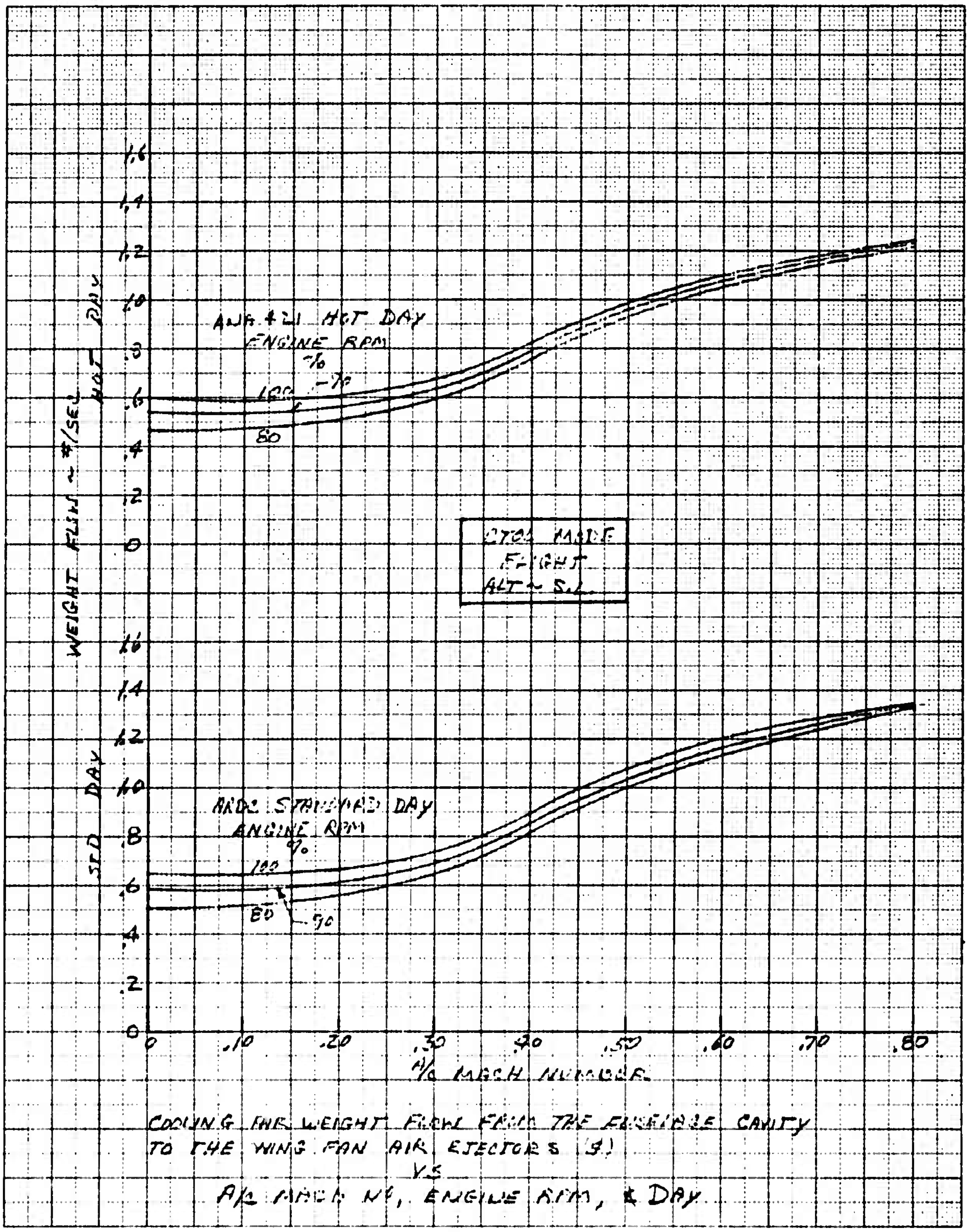

Figure 7.57 Cooling Air Weight Flow - Center Fuselage to Wing Fan Cavities Vs Aircraft Mach No. and % RPM - Conventional Flight Mode, Standard and Hot Day, Sea Level

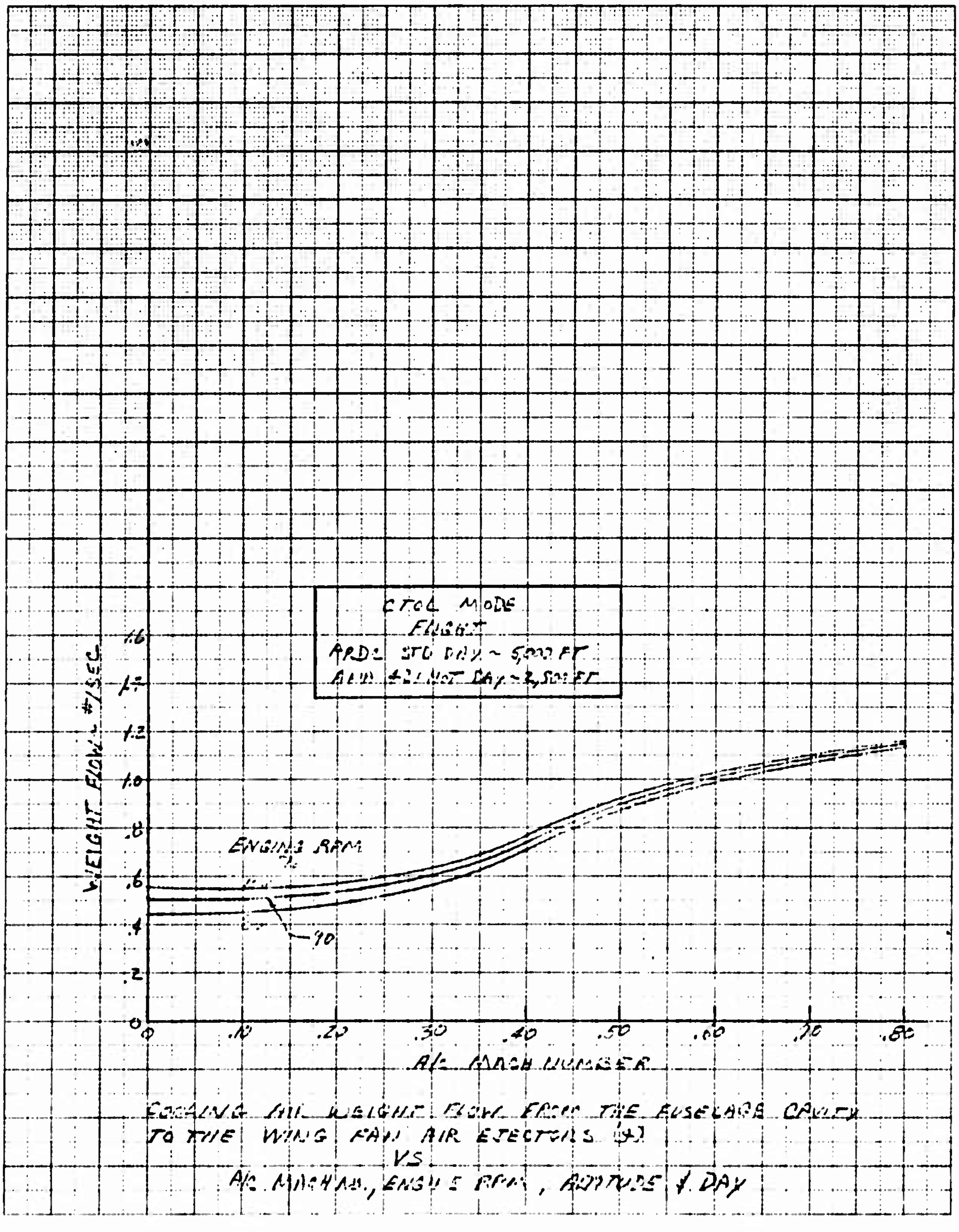

Figure 7.58 Cooling Air Weight Flow - Center Fuselage to Wing Fan Cavities Vs Aircraft Mach No. and % RPM - Conventional Flight Mode, Standard Day 5,000 Ft. and Hot Day 2,500 Ft.

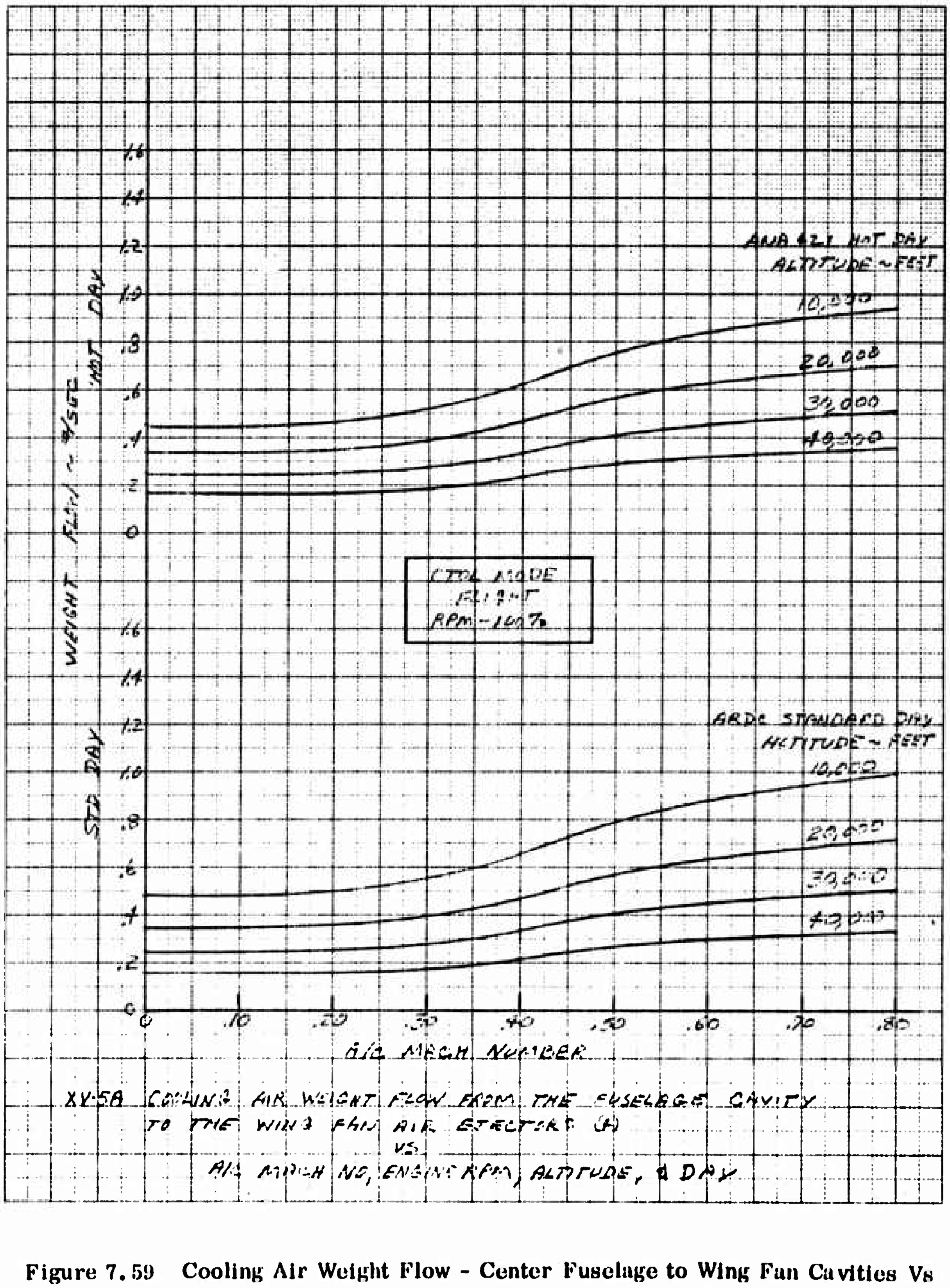

Figure 7.59 Cooling Air Weight Flow - Center Fuselage to Wing Fan Cavities Vs Aircraft Mach No. and Altitude - Conventional Flight Mode, Standard and Hot Day

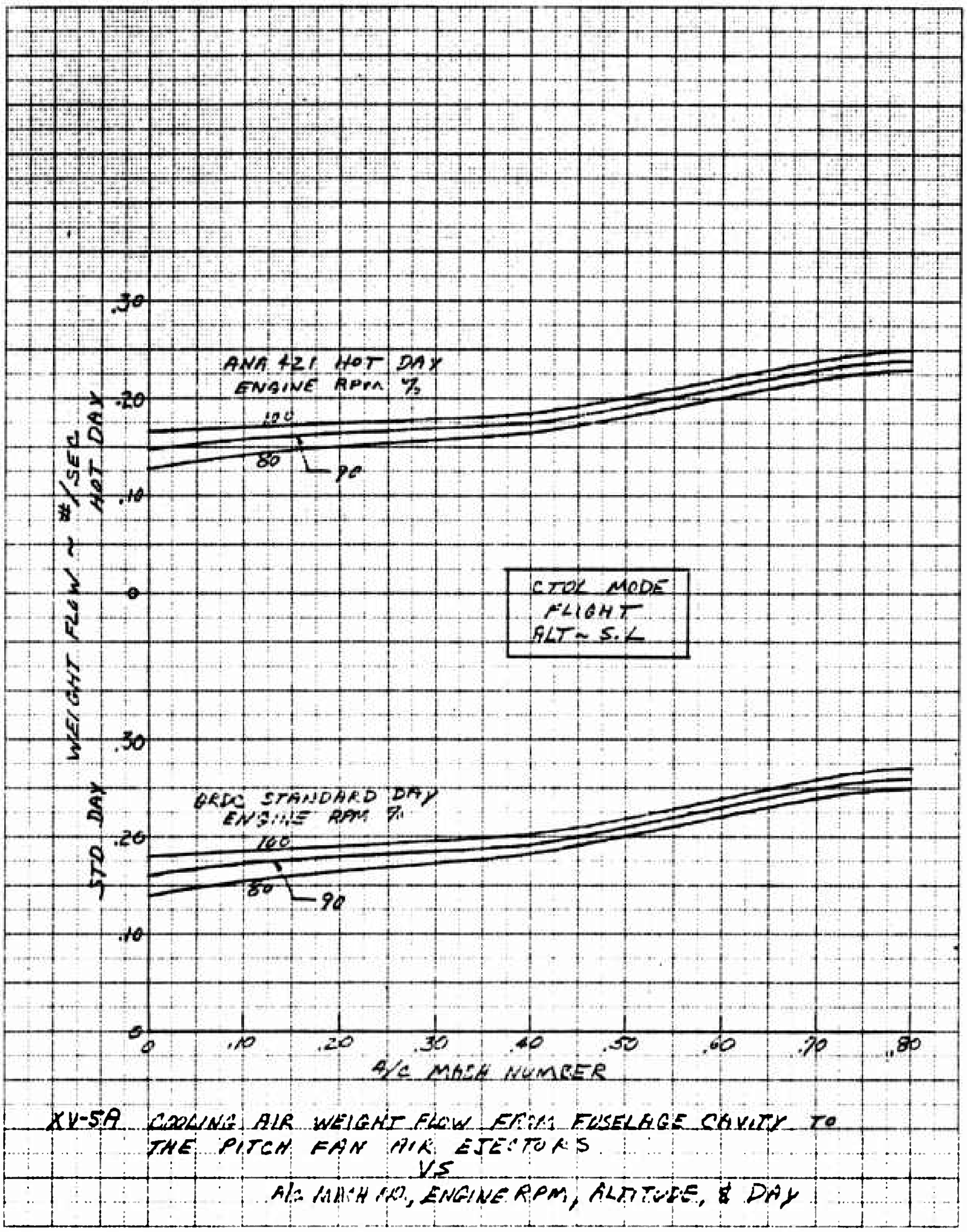

Figure 7.60 Cooling Air Weight Flow - Forward Fuselage to Nose Fan Cavity Vs Aircraft Mach No. and % RPM - Conventional Flight Mode, Standard and Hot Day, Sea Level

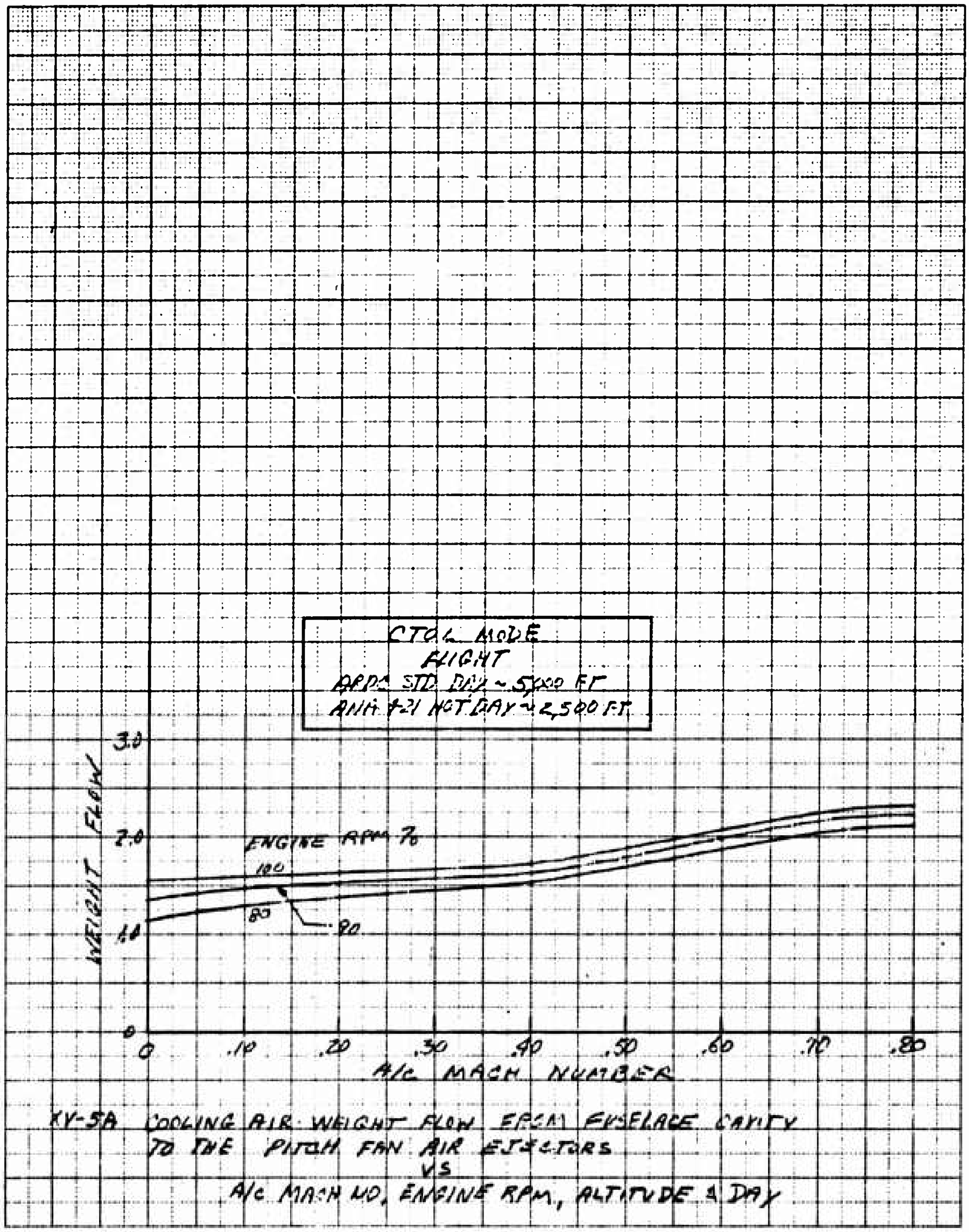

Figure 7.61 Cooling Air Weight Flow - Forward Fuselage to Nose Fan Cavity Vs Aircraft Mach No. and % RPM - Conventional Flight Mode, Standard Day 5,000 Ft. and Hot Day 2,500 Ft.

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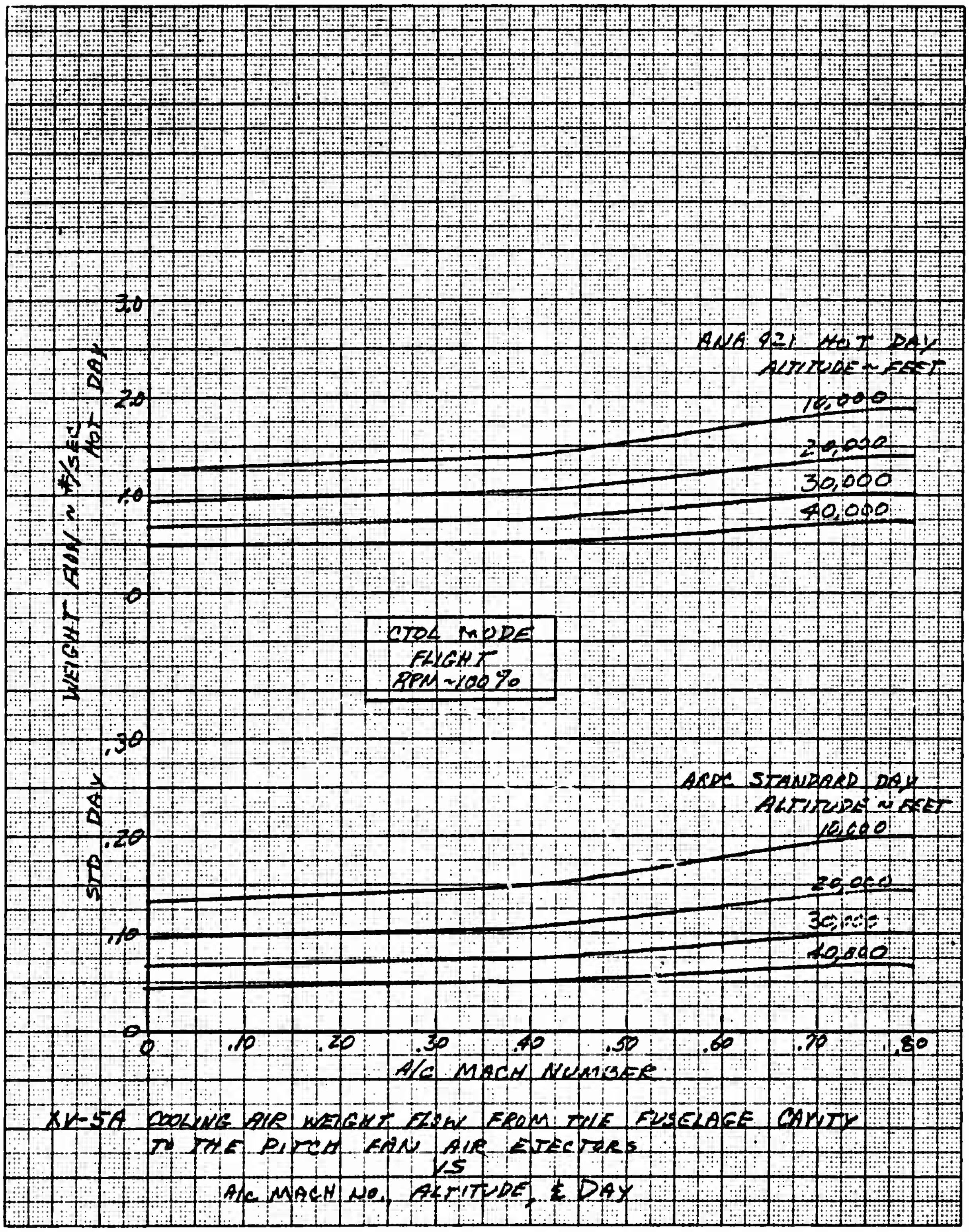

Figure 7.62 Cooling Air Weight Flow - Forward Fuselage to Nose Fan Cavity Vs Aircraft Mach No. and Altitude - Conventional Flight Mode, 100% RPM, Standard and Hot Day

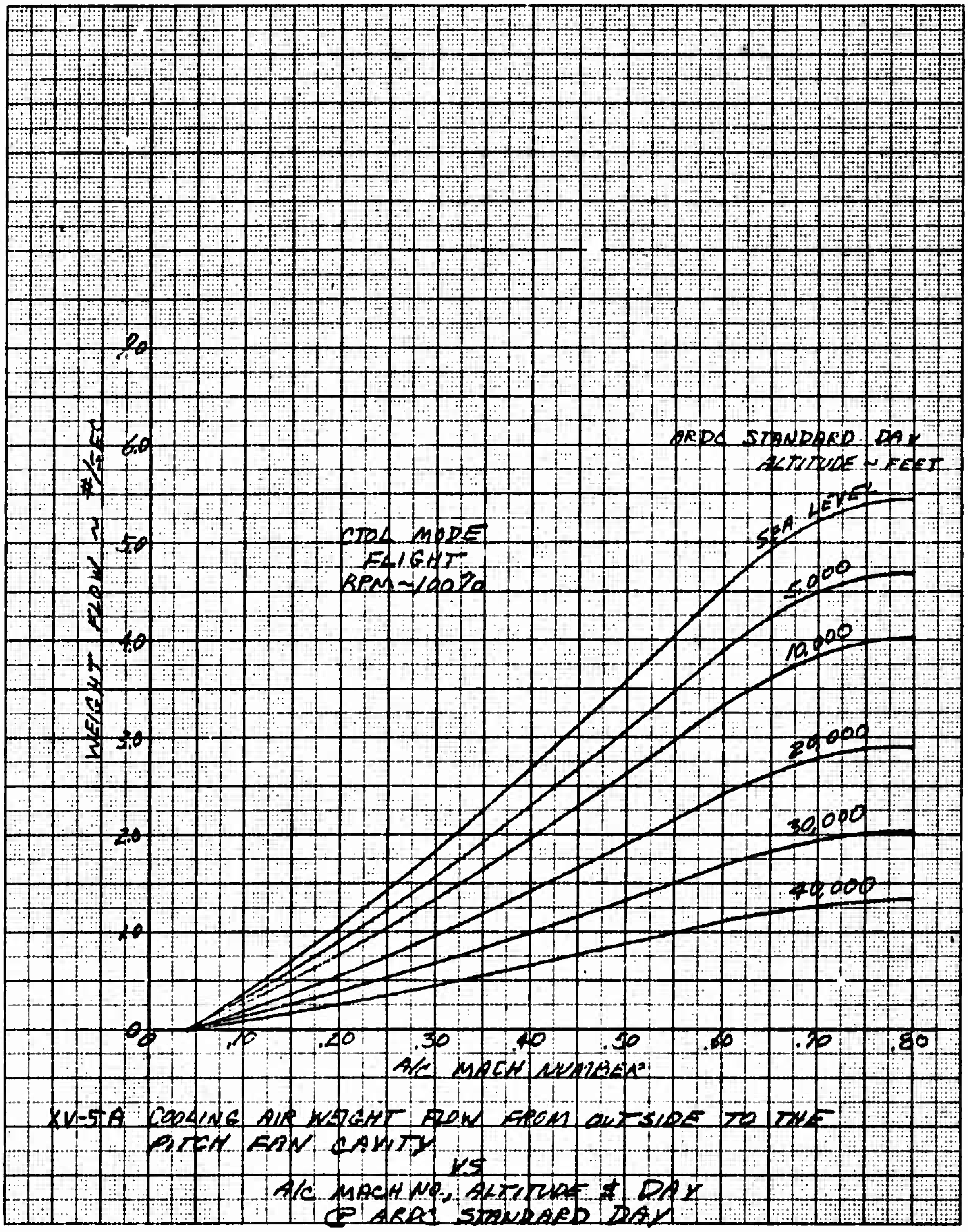

Figure 7.63 Cooling Air Weight Flow - Outside to Nose Fan Cavity Vs Aircraft Mach No. and Altitude - Conventional Flight Mode, 100% RPM, Standard Day

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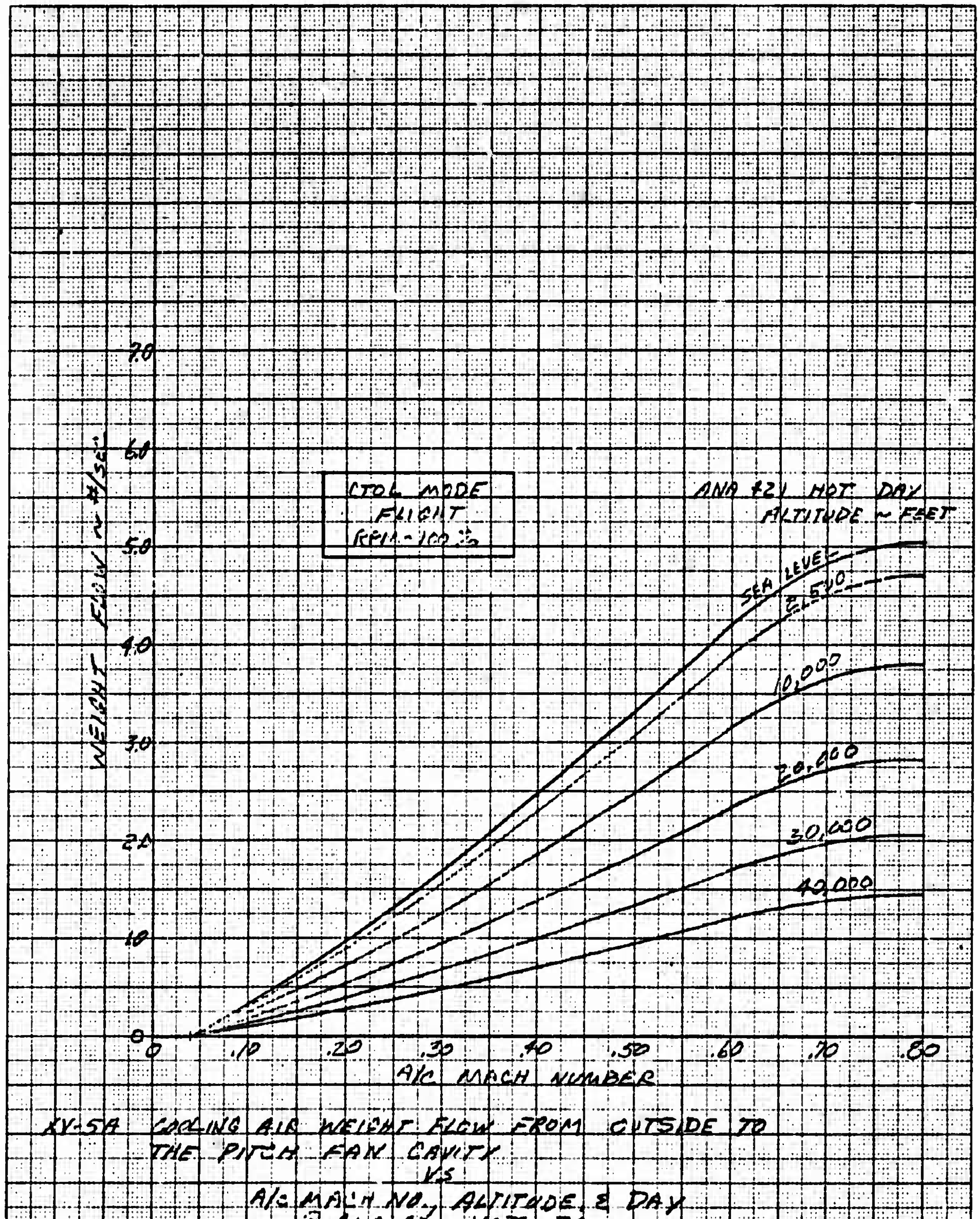

Figure 7.64 Cooling Air Weight Flow - Outside to Nose Fan Cavity Vs Aircraft Mach No. and Altitude - Conventional Flight Mode, 100% RPM, Hot Day

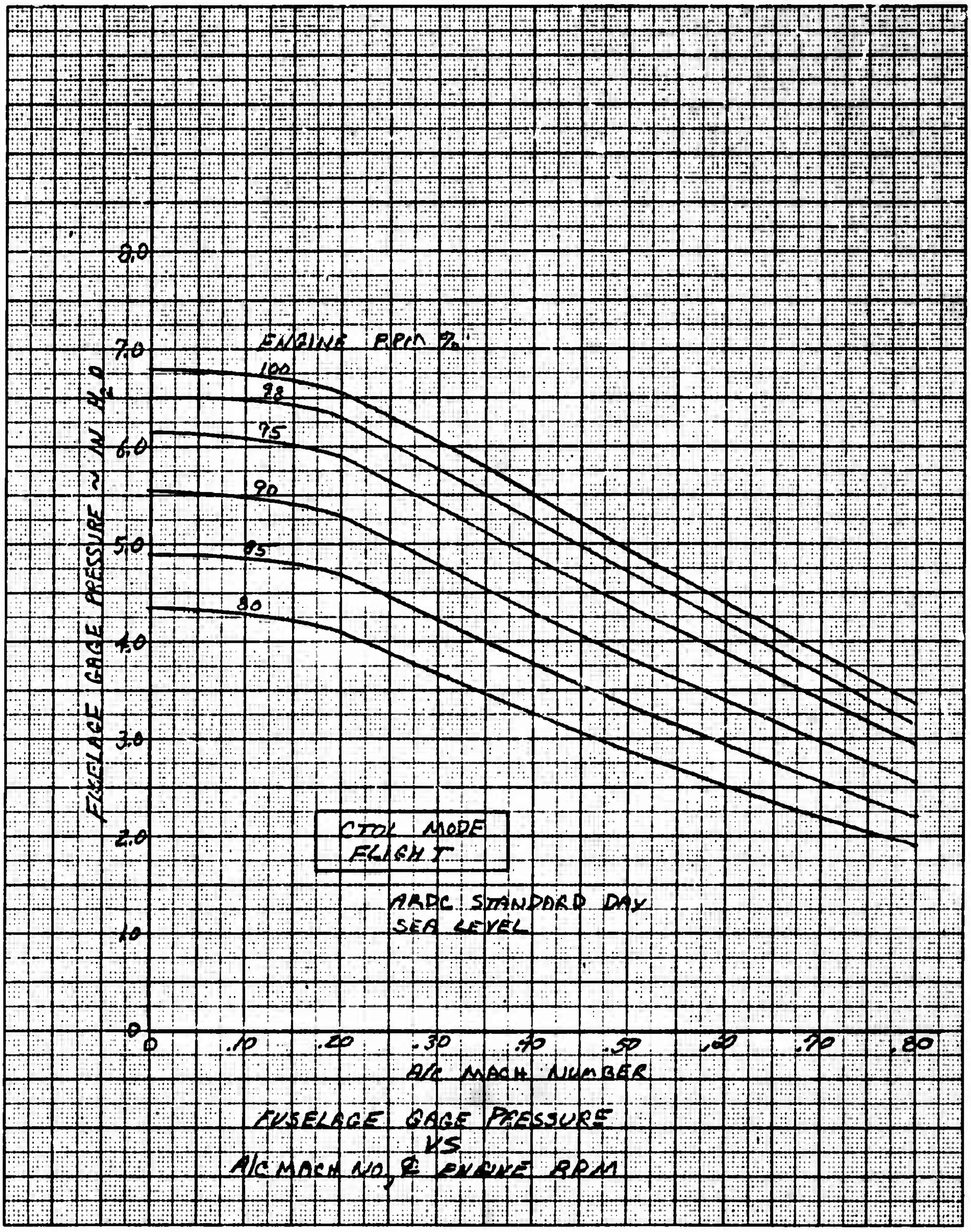

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Figure 7.65 Center Fuselage Gage Pressure Vs Aircraft Mach No. and % RPM - Conventional Flight Mode, Standard Day

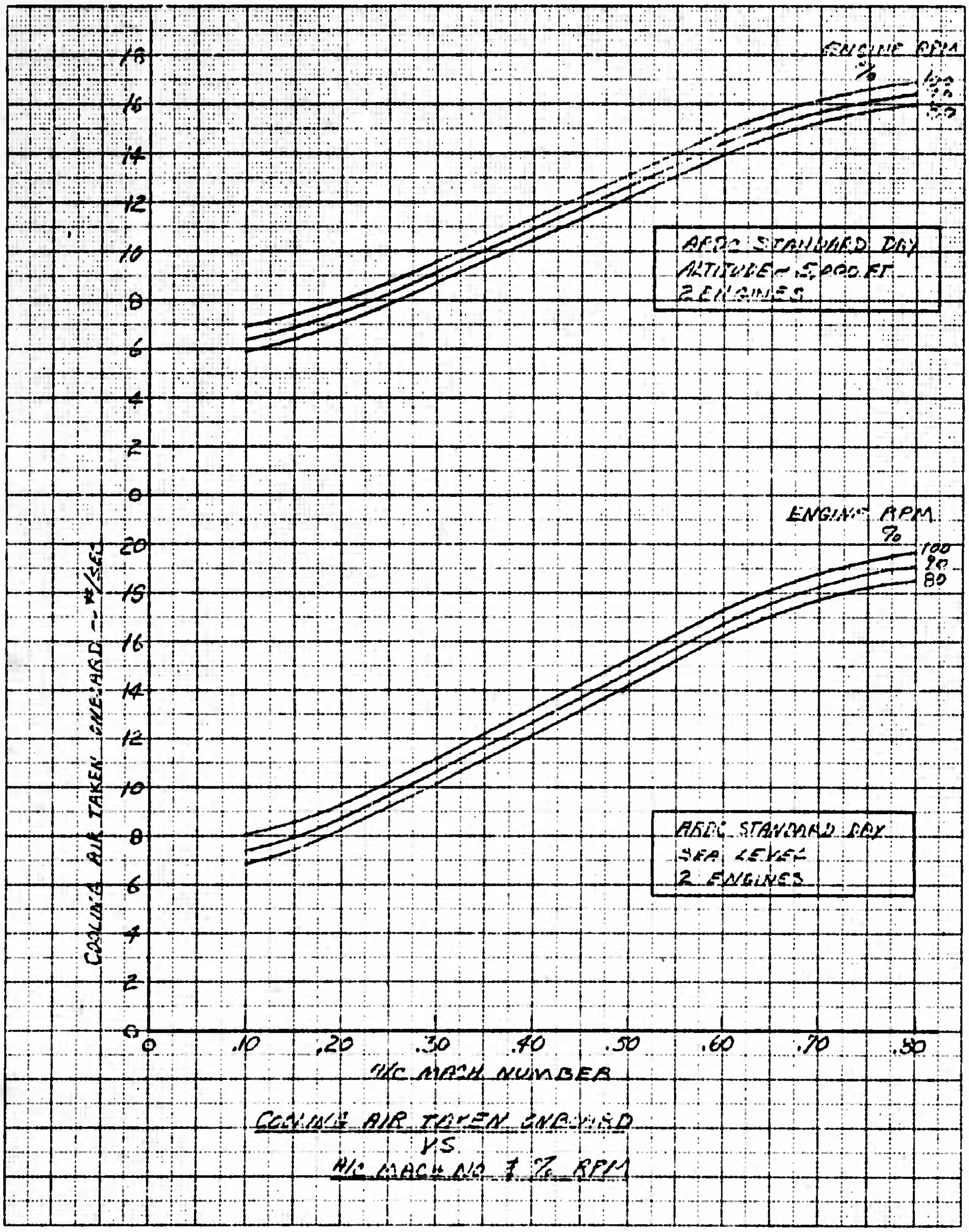

Figure 7.66 Cooling Air Taken Onboard Vs Aircraft Mach No. and % RPM - Conventional Mode, 2 Engines, Standard Day, Sea Level and 5,000 Ft.

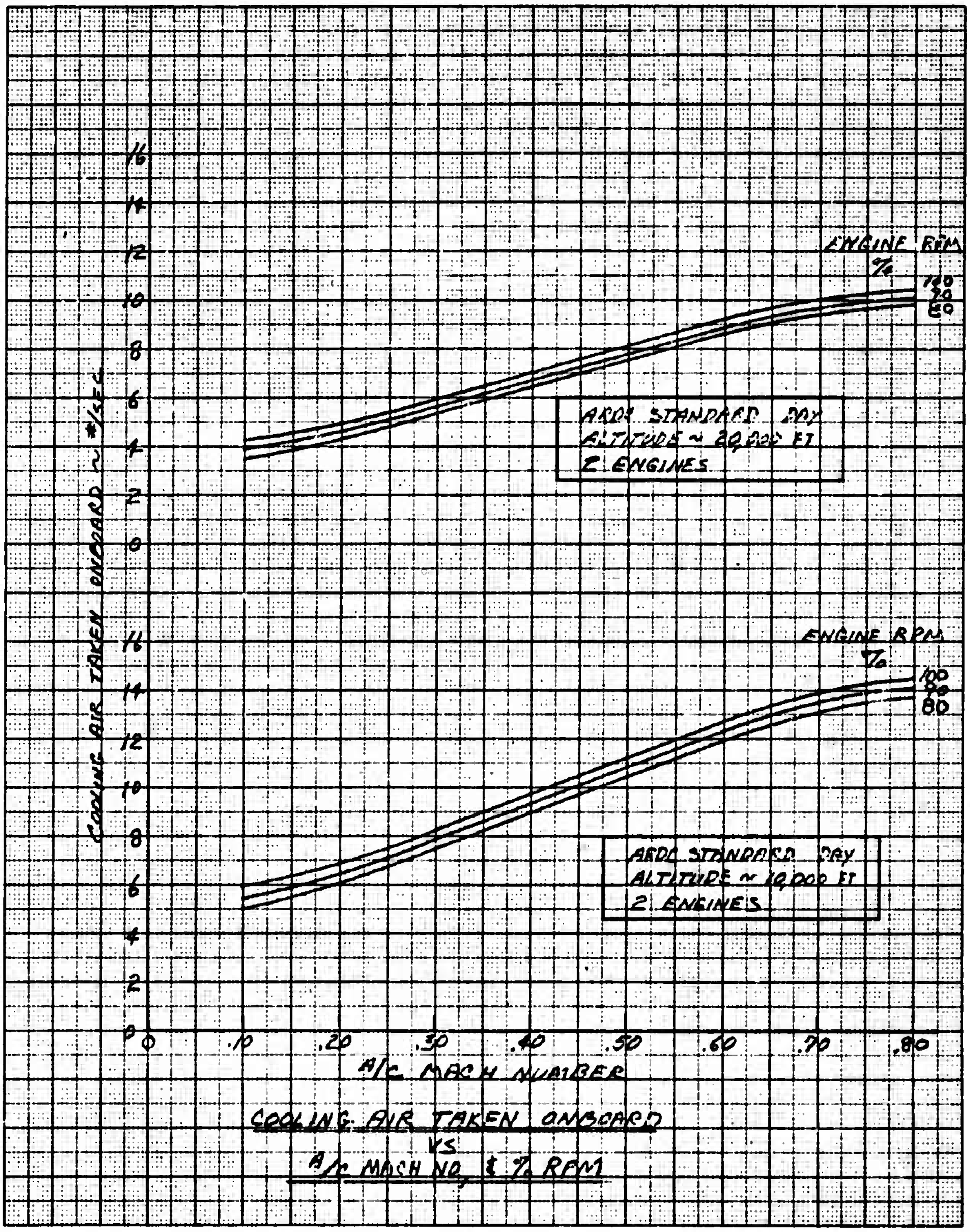

Figure 7.67 Cooling Air Taken Onboard Vs Aircraft Mach No. and % RPM - Conventional Mode, 2 Engines, Standard Day, 10,000 and 20,000 Ft.

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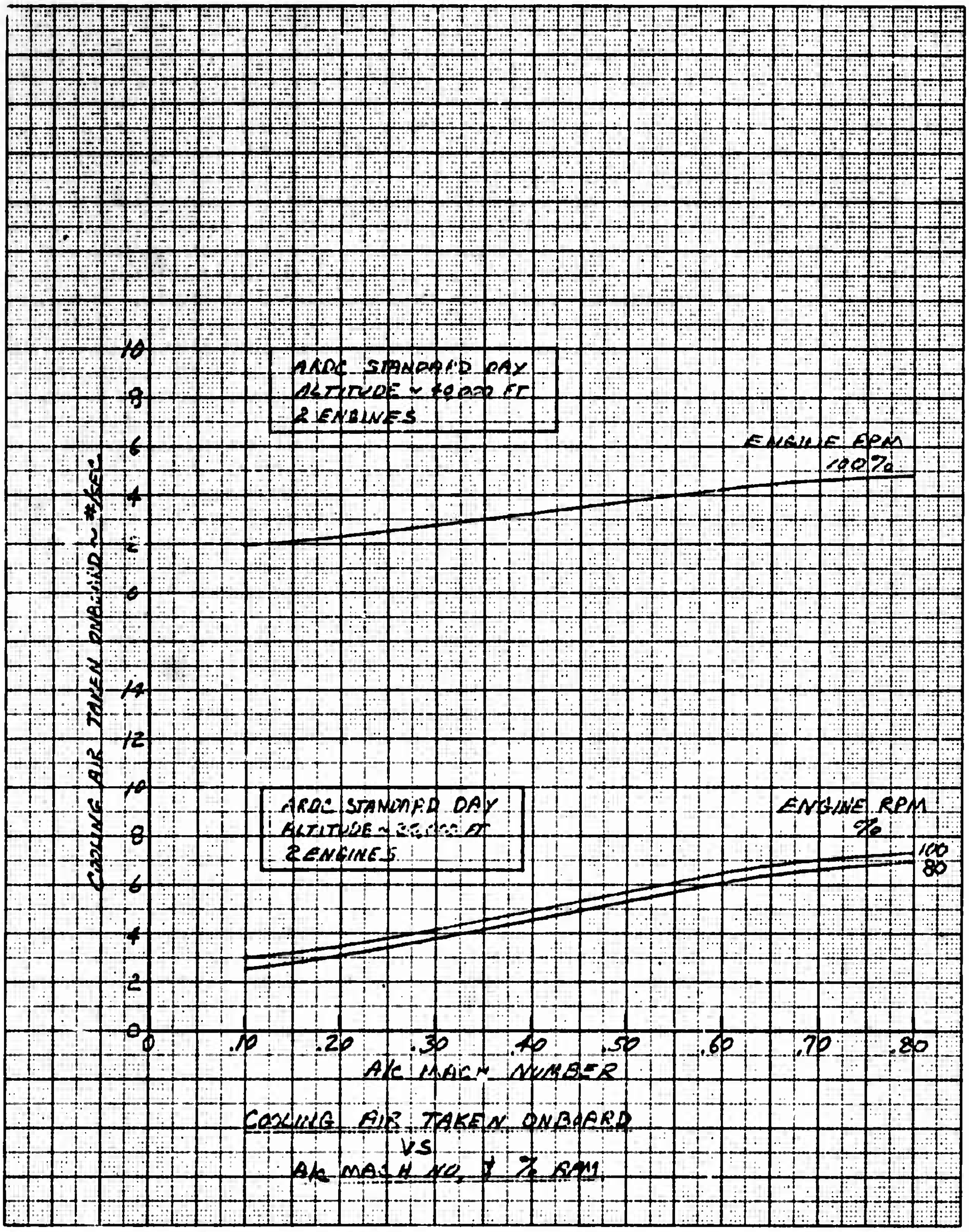

Figure 7.68 Cooling Air Taken Onboard Vs Aircraft Mach No. and % RPM - Conventional Mode, 2 Engines, Standard Day, 30,000 and 40,000 Ft.

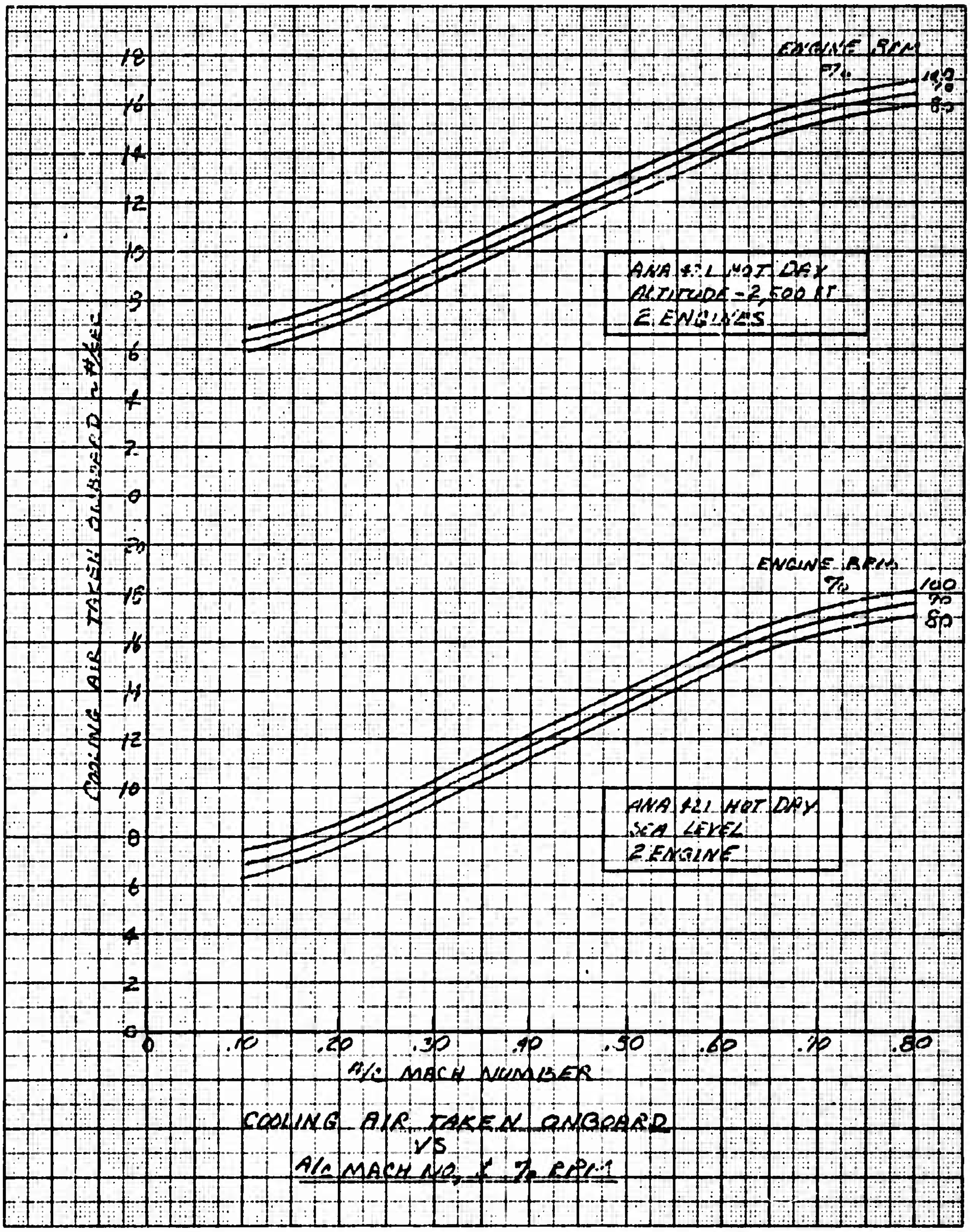

Figure 7.69 Cooling Air Taken Onboard Vs Aircraft Mach No. and % RPM - Conventional Mode, 2 Engines, Hot Day, Sea Level, and 2,500 Ft.

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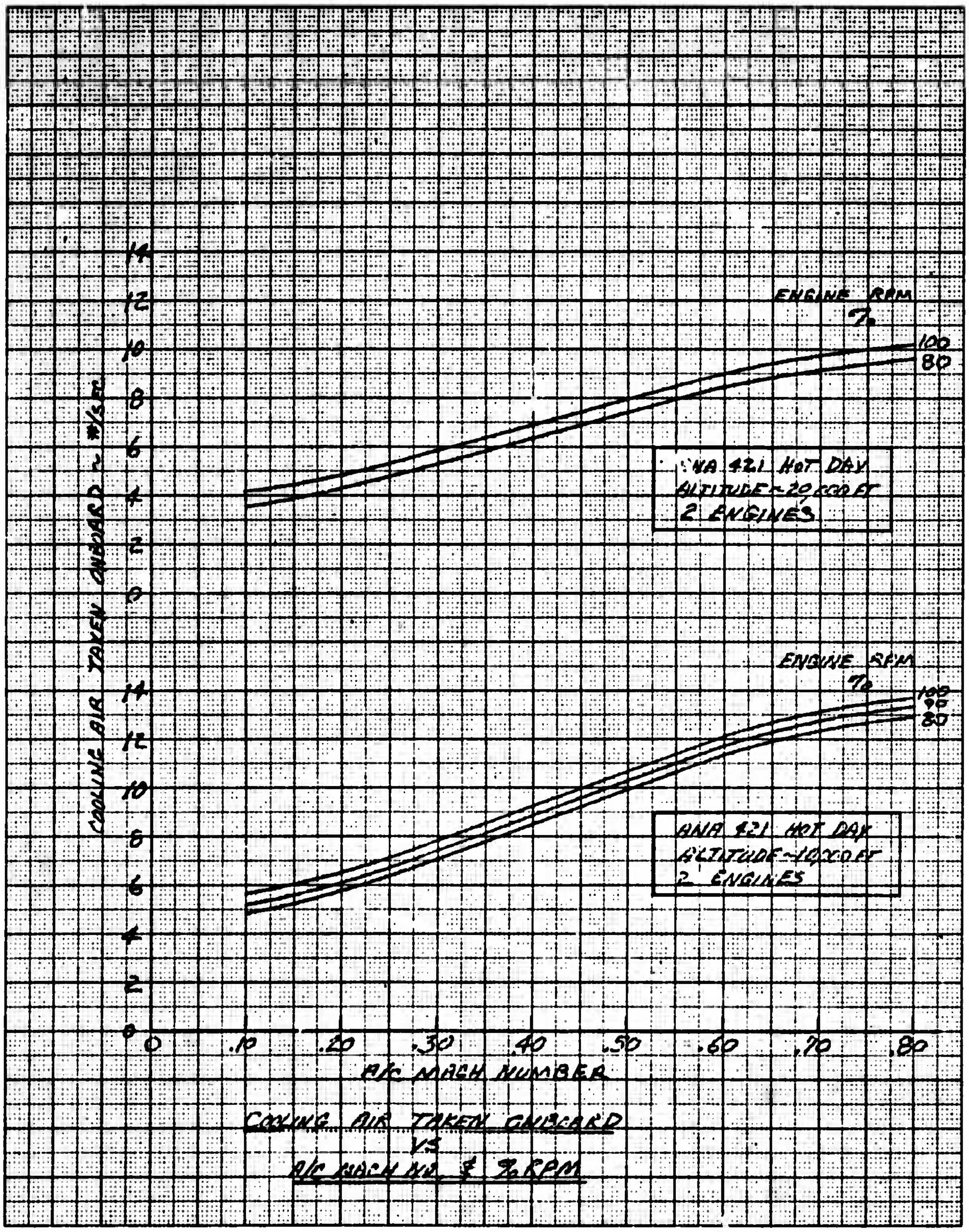

Figure 7.70 Cooling Air Taken Onboard Vs Aircraft Mach No. and % RPM - Conventional Mode, 2 Engines, Hot Day, 10,000 and 20,000 Ft.

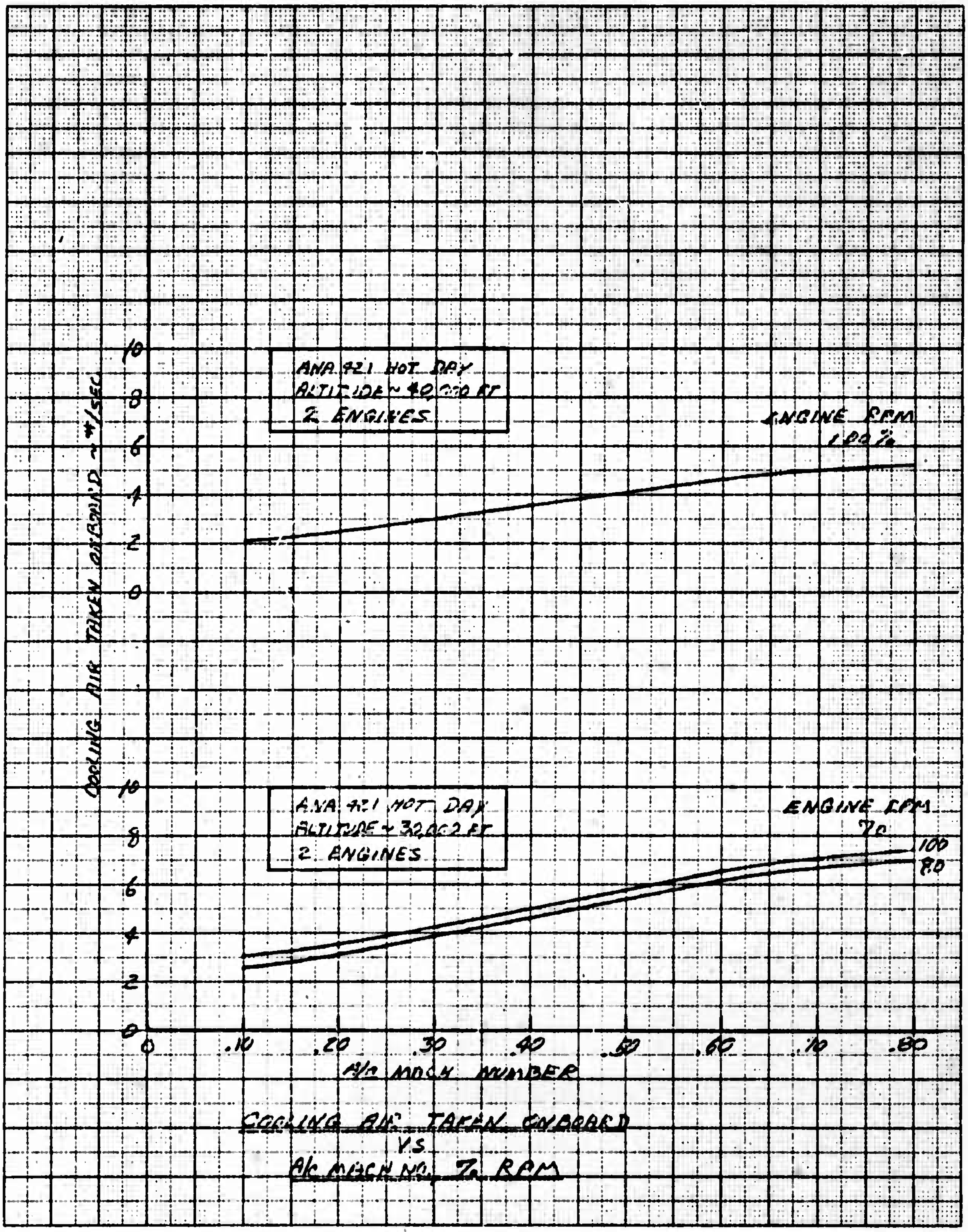

Figure 7.71 Cooling Air Taken Onboard Vs Aircraft Mach No. and % RPM - Conventional Mode, 2 Engines, Hot Day, 30,000 and 40,000 Ft.

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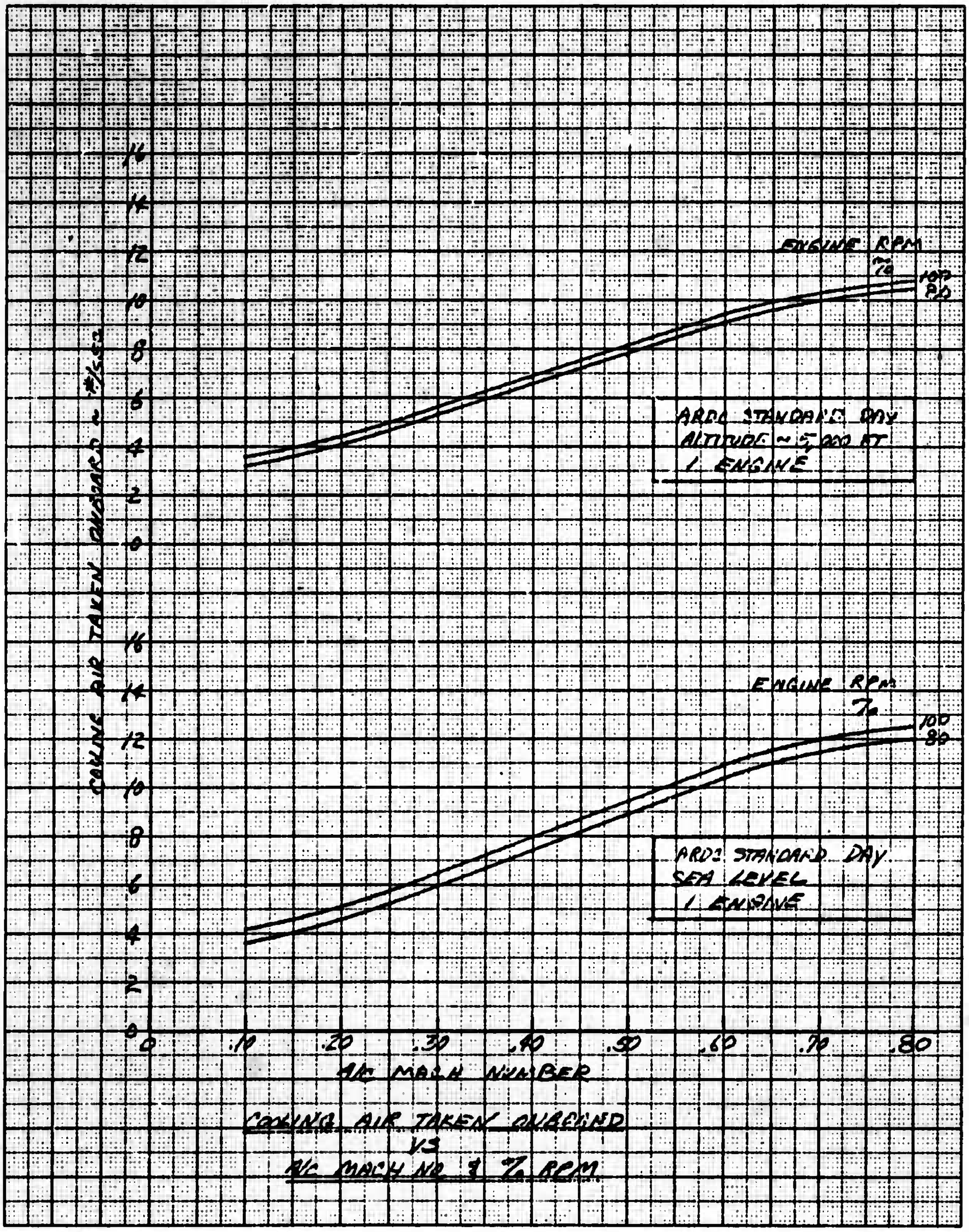

Figure 7.72 Cooling Air Taken Onboard Vs Aircraft Mach No. and % RPM - Conventional Mode, 1 Engine, Standard Day, Sea Level and 5,000 Ft.

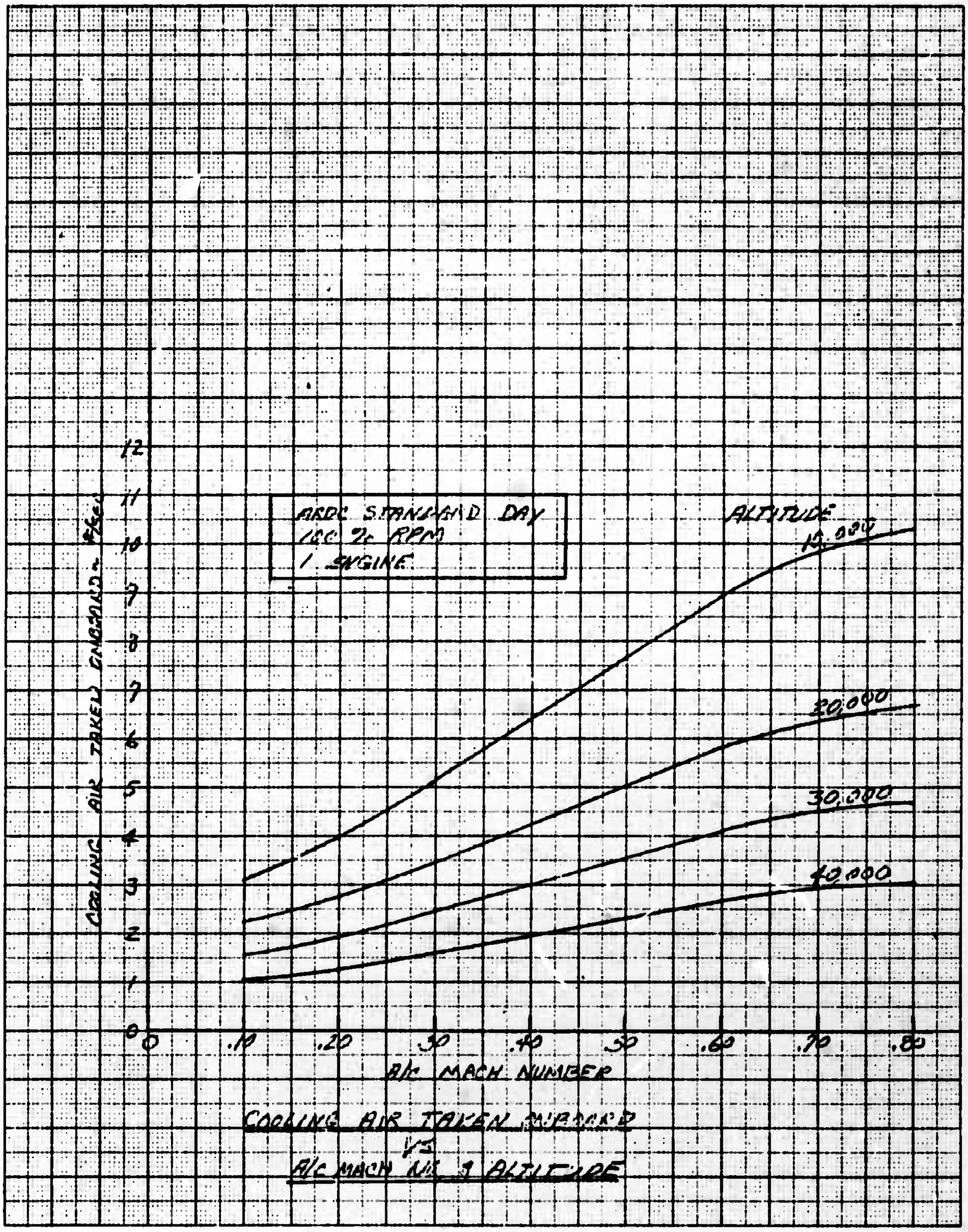

Figure 7.73 Cooling Air Taken Onboard Vs Aircraft Mach No. and Altitude - Conventional Mode, 1 Engine, Standard Day, 100% RPM

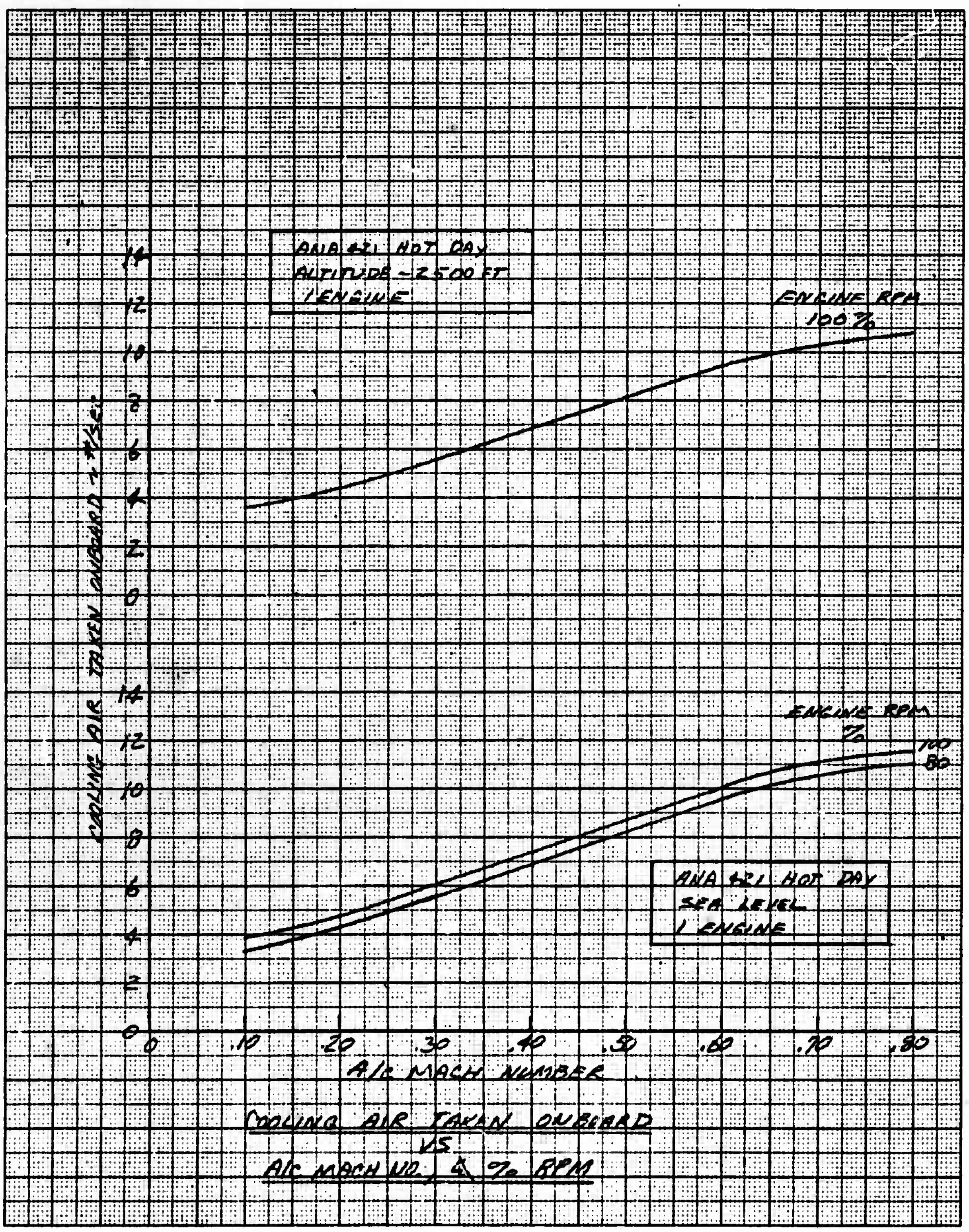

Figure 7.74 Cooling Air Taken Onboard Vs Aircraft Mach No. and % RPM - Conventional Mode, 1 Engine, Hot Day, Sea Level, 2,500 Ft.

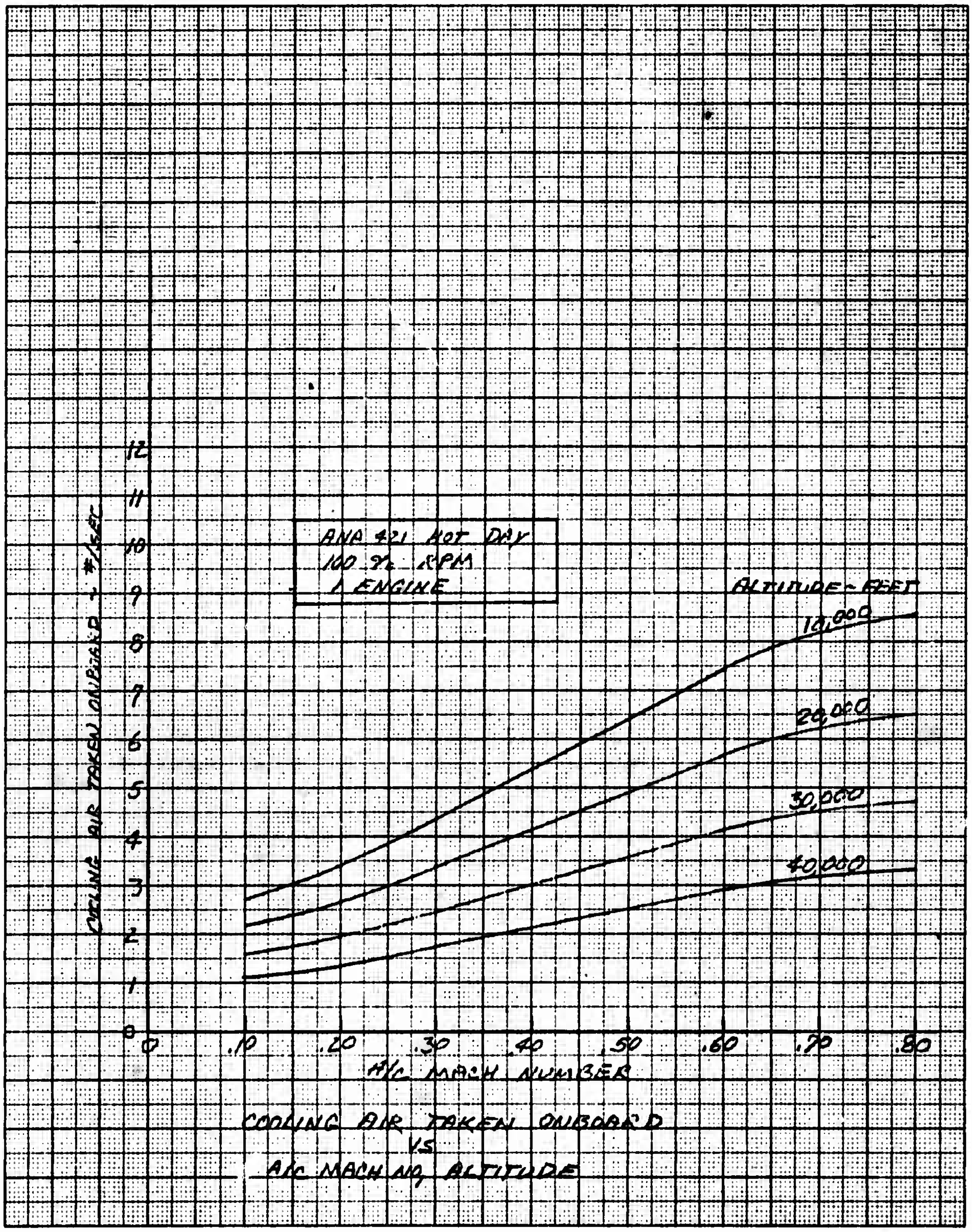

Figure 7.75 Cooling Air Taken Onboard Vs Aircraft Mach No. and Altitude - Conventional Mode, 1 Engine, Hot Day, 100% RPM

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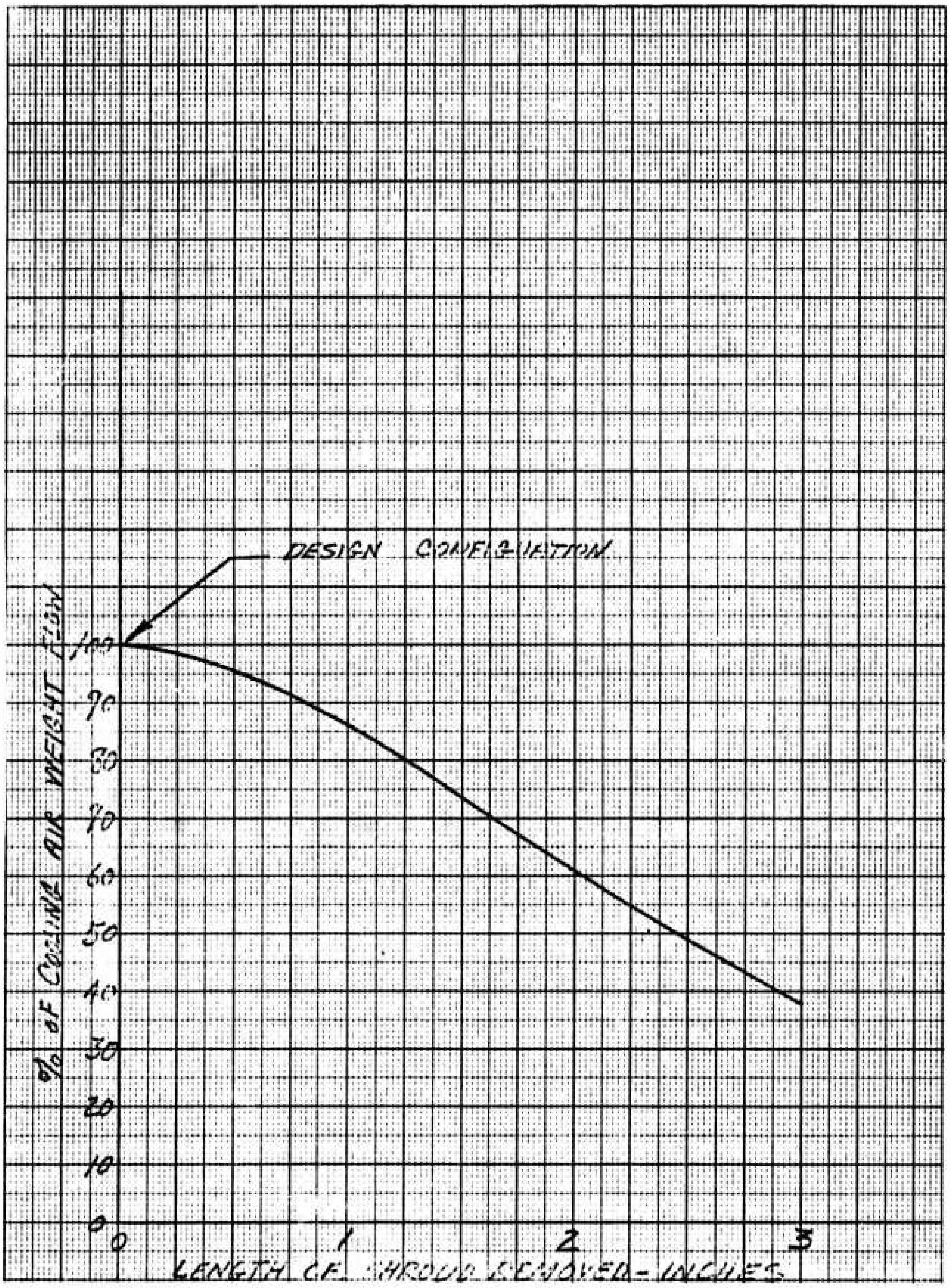

Figure 7.76 Tailpipe Ejector Cooling Air Weight Flow Vs Shroud Length

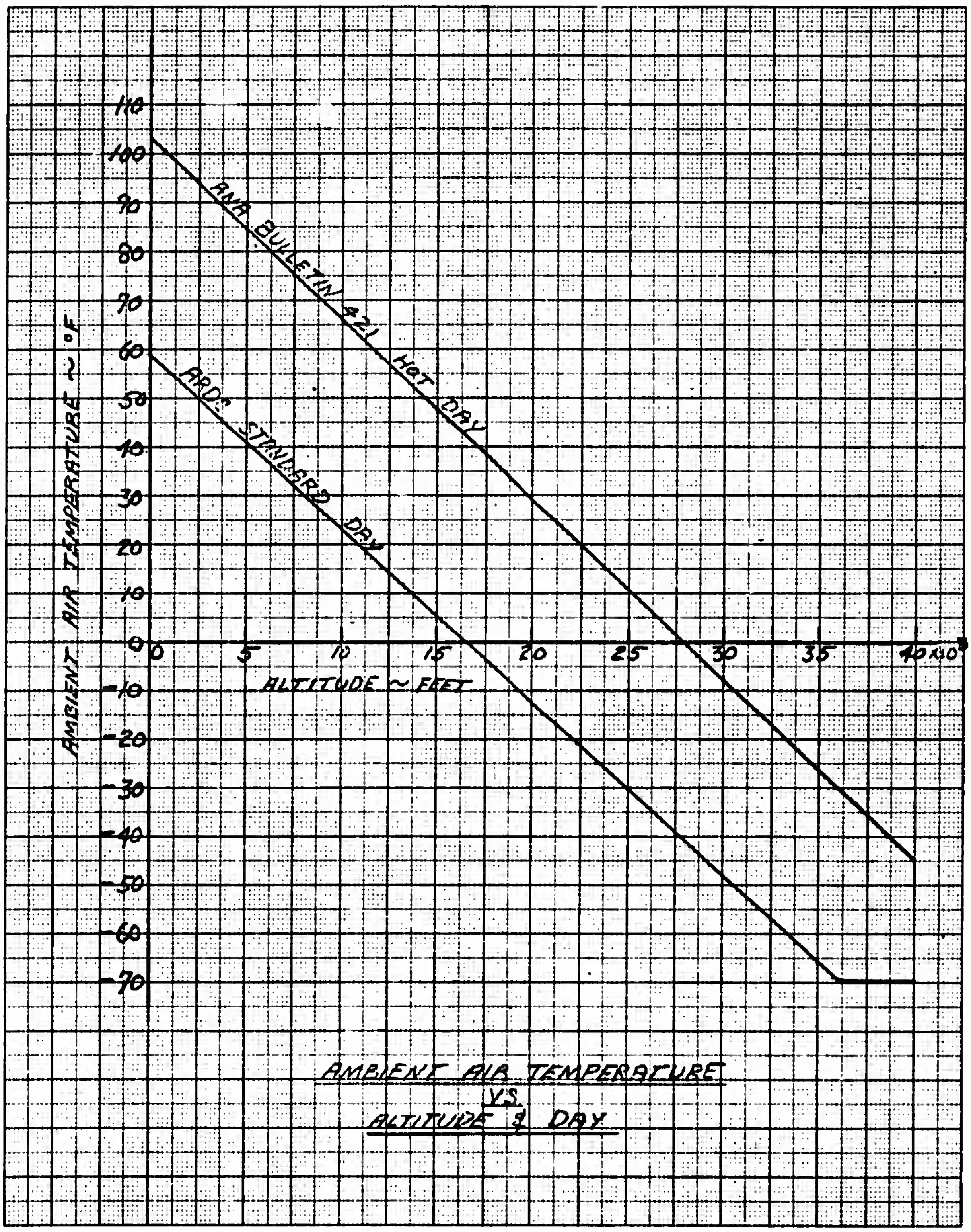

Figure 7.77 Ambient Air Temperature Vs Altitude and Day

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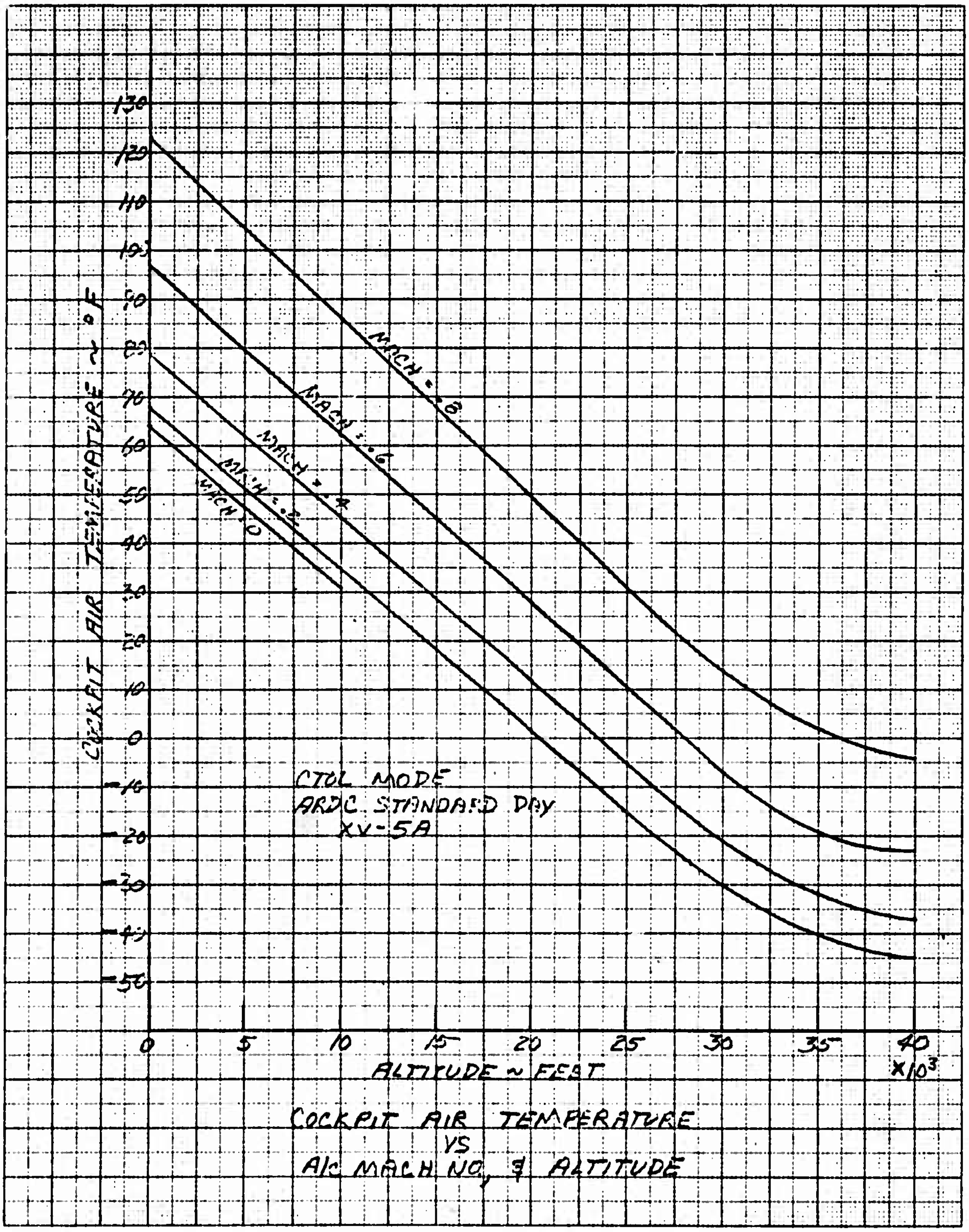

Figure 7.78 Cockpit Air Temperature Vs Aircraft Mach No. and Altitude - Conventional Mode, Standard Day

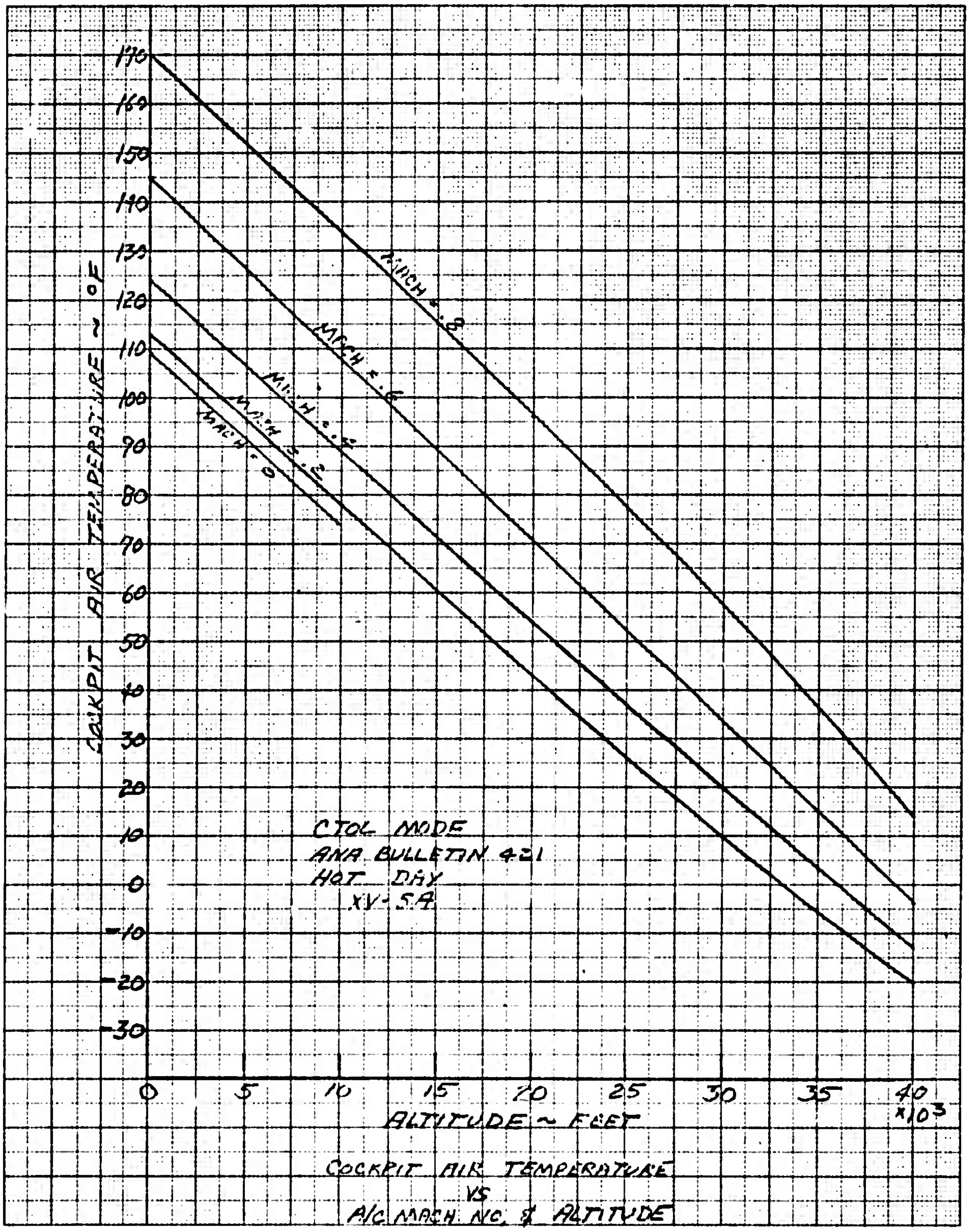

Figure 7.79 Cockpit Air Temperature Vs Aircraft Mach No. and Altitude - Conventional Mode, Hot Day

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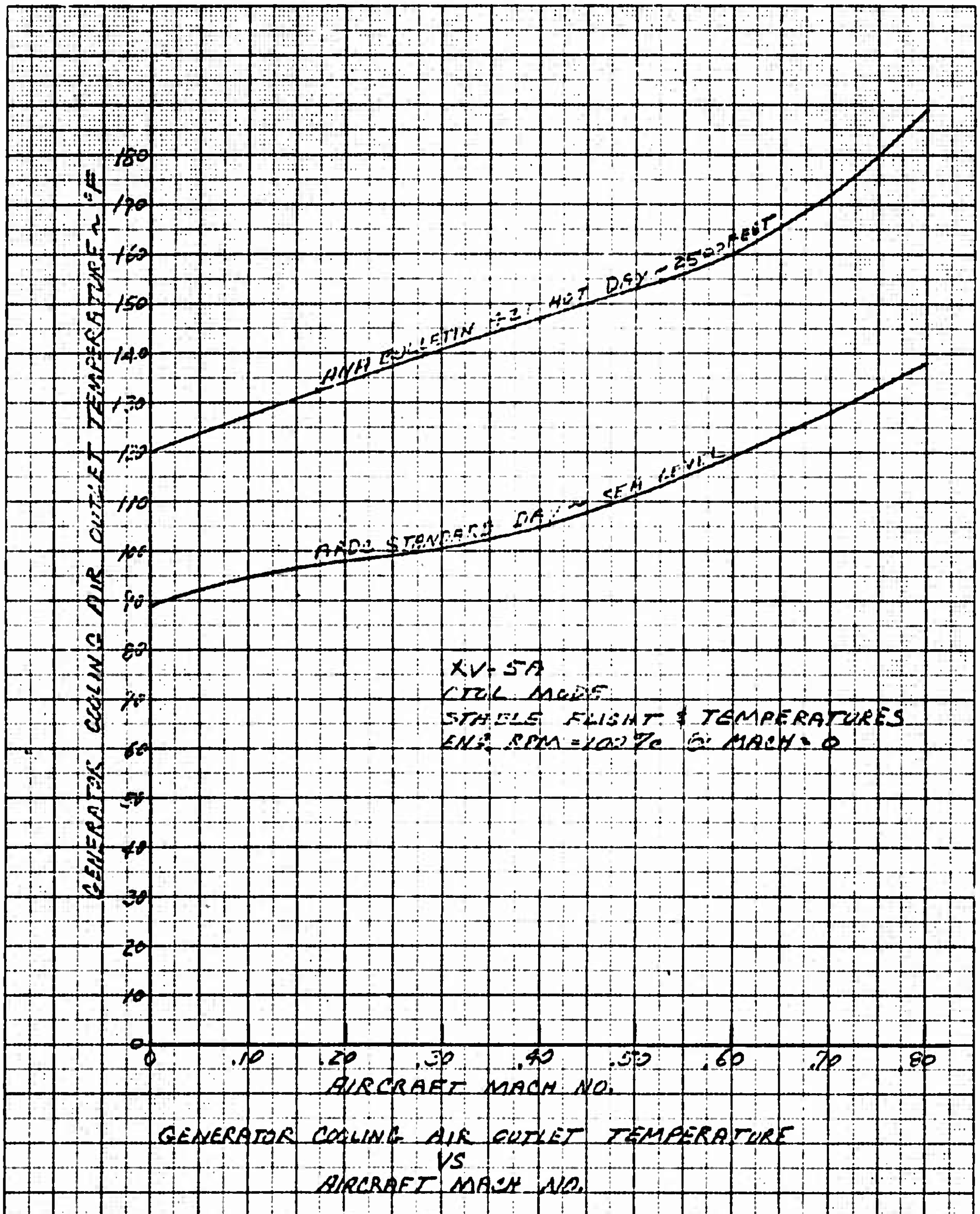

Figure 7.80 Generator Cooling Air Outlet Temperature Vs Aircraft Mach No. - Conventional Steady Flight, Standard Day Sea Level, and Hot Day 2,500 Ft.

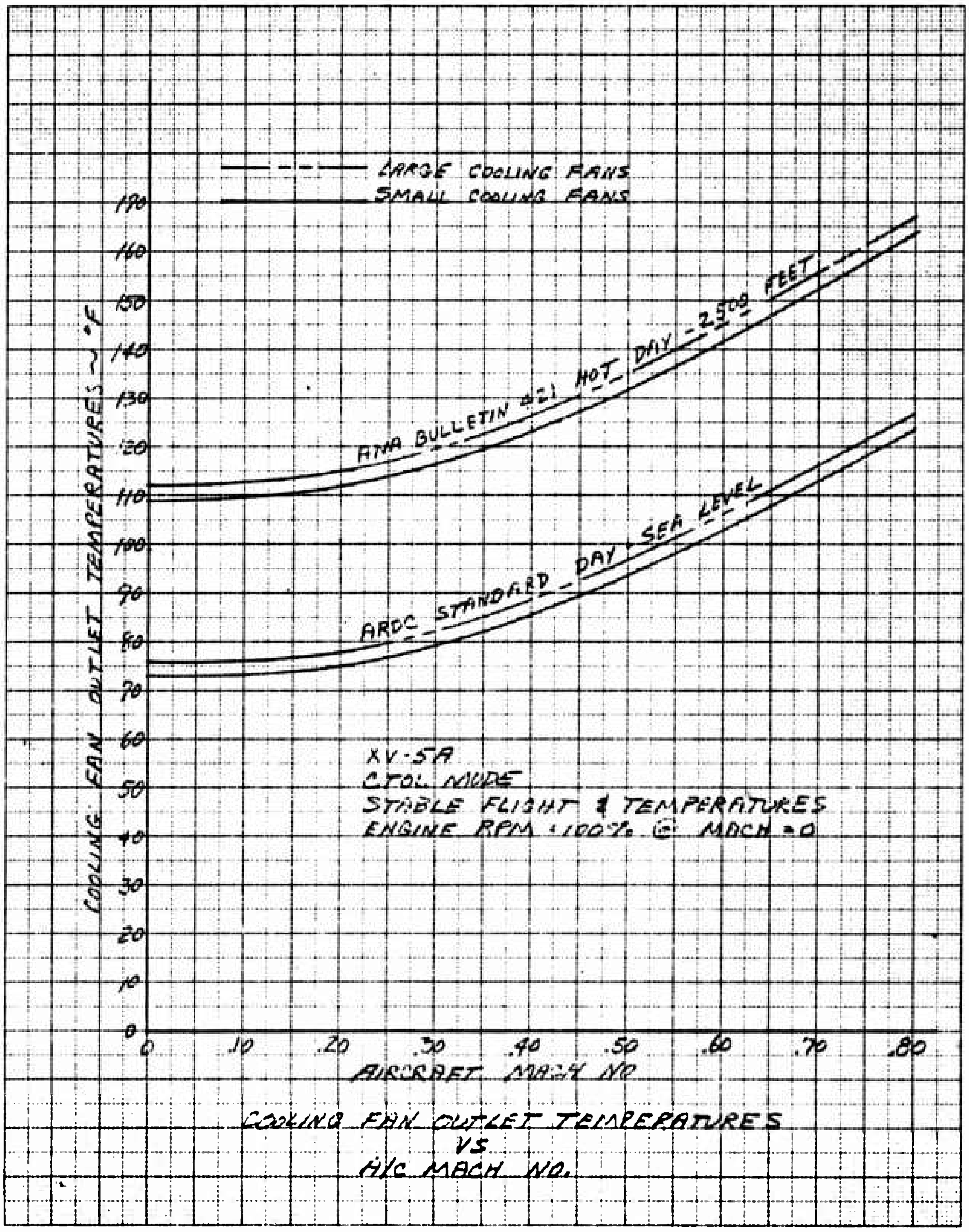

Figure 7.81 Cooling Fan Exhaust Temperature Vs Aircraft Mach No. - Conventional Steady Flight, Standard Day Sea Level, and Hot Day 2,500 Ft.

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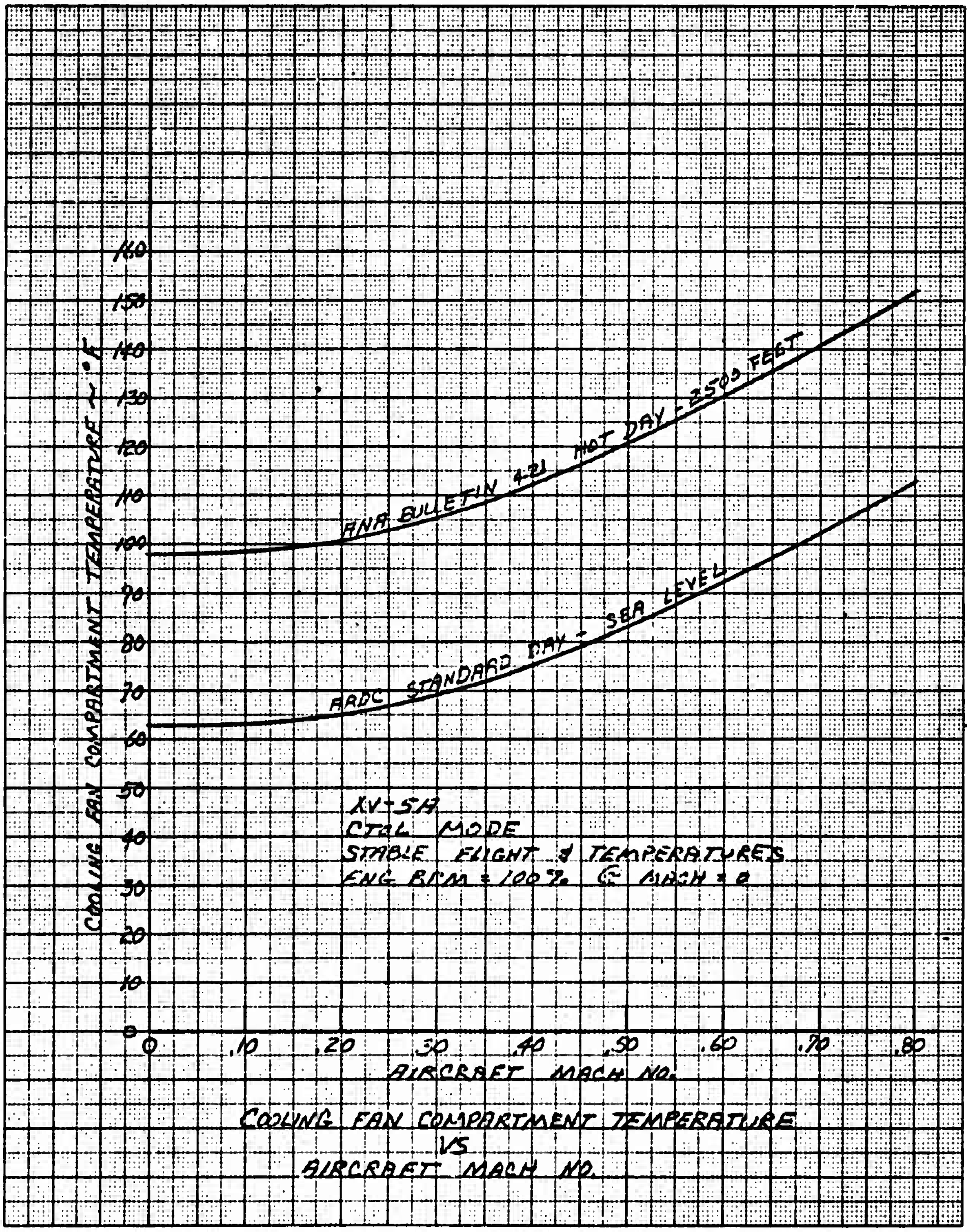

Figure 7.82 Cooling Fan Compartment Air Temperature Vs Aircraft Mach No. - Conventional Steady Flight, Standard Day Sea Level, and Hot Day, 2,500 Ft.

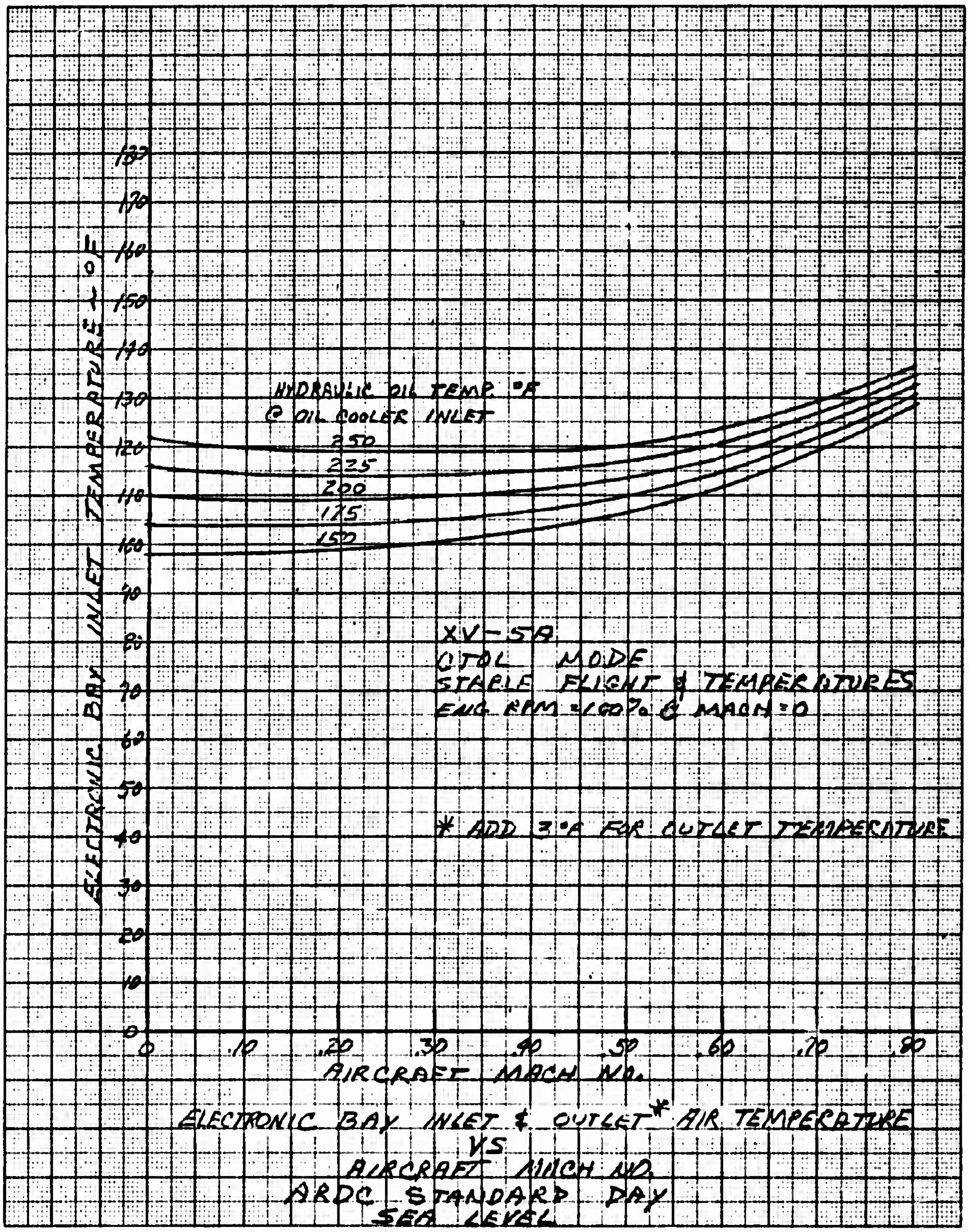

Figure 7.83 **Electronic Compartment Air Temperature Vs Aircraft Mach No. and Hydraulic Oil Temperature - Conventional Steady Flight, Standard Day Sea Level**

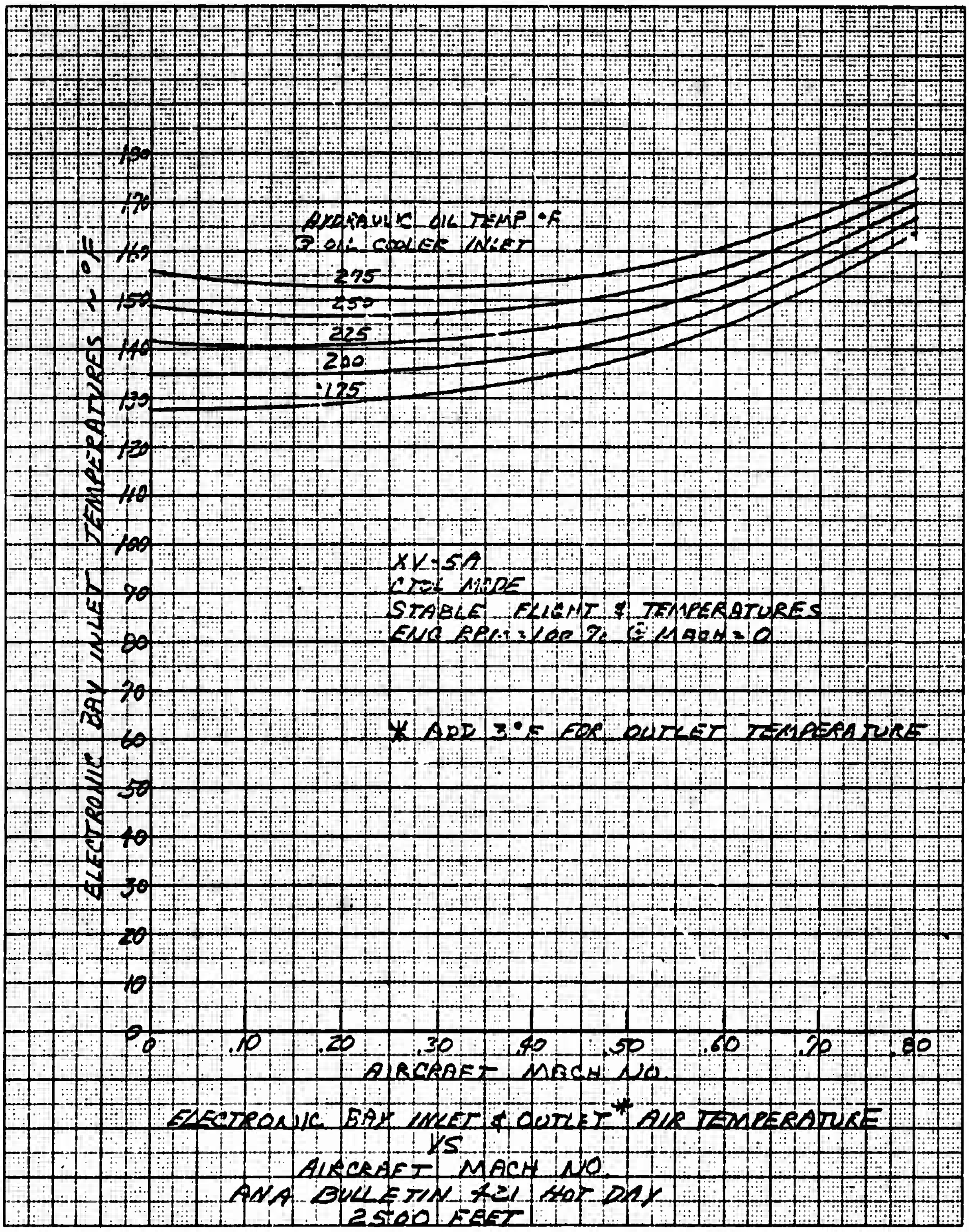

Figure 7.84 Electronic Compartment Air Temperature Vs Aircraft Mach No. and Hydraulic Oil Temperature - Conventional Steady Flight, Hot Day 2,500 Ft.

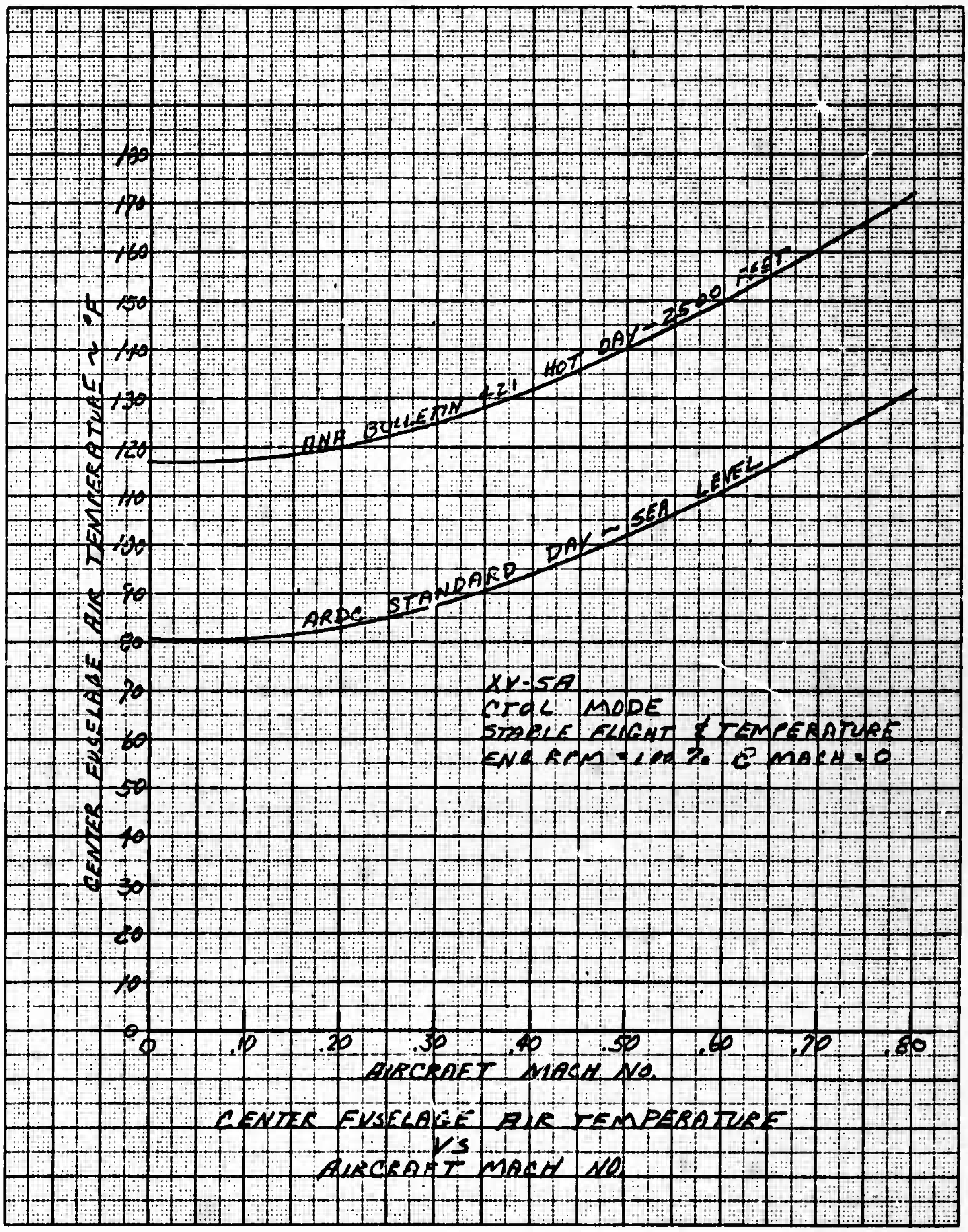

Figure 7.85 Center Fuselage Air Temperature Vs Aircraft Mach No. - Conventional Steady Flight, Standard Day Sea Level and Hot Day 2,500 Ft.

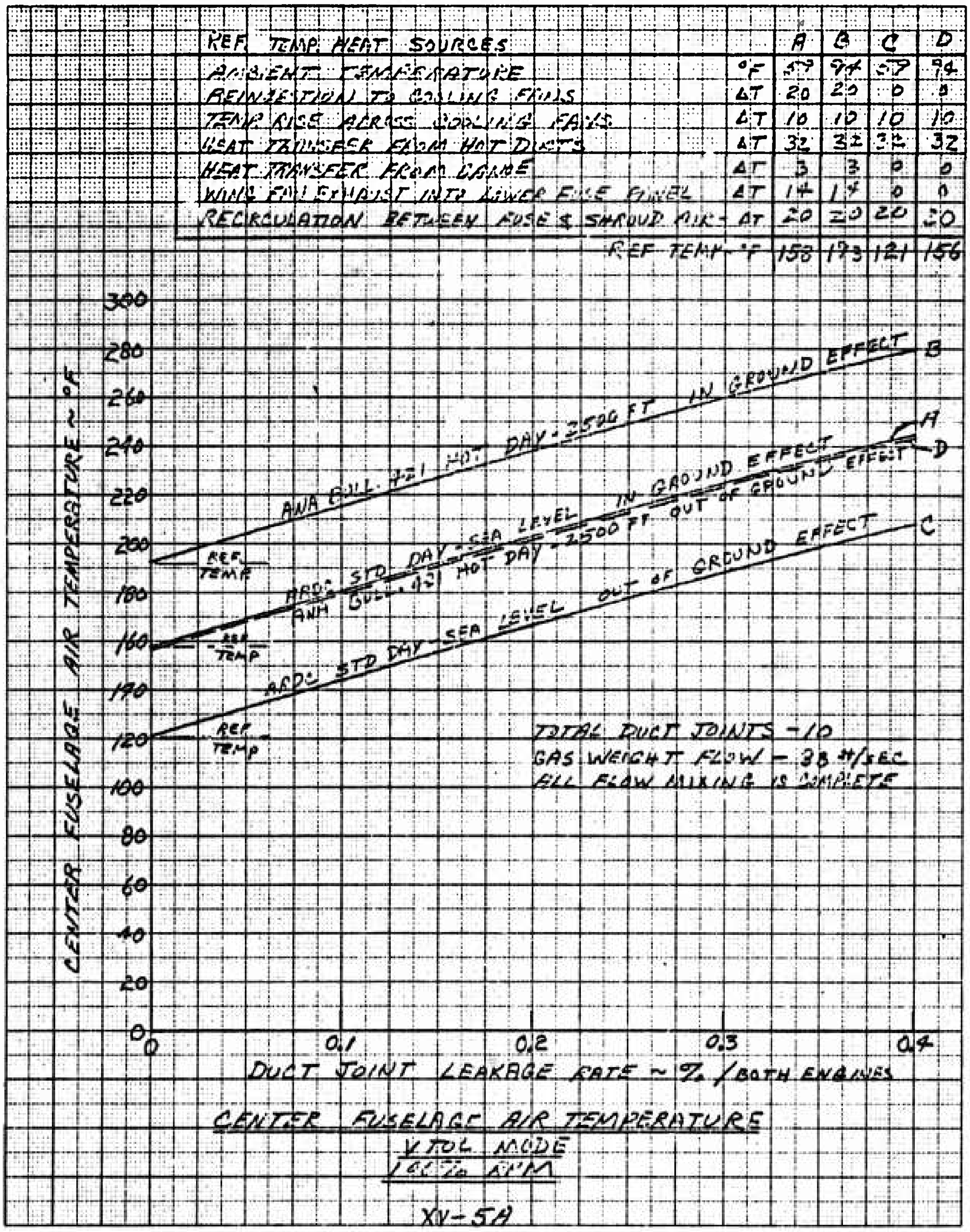

Figure 7.86 Center Fuselage Air Temperature - Fan Mode, 100% RPM, Standard and Hot Day

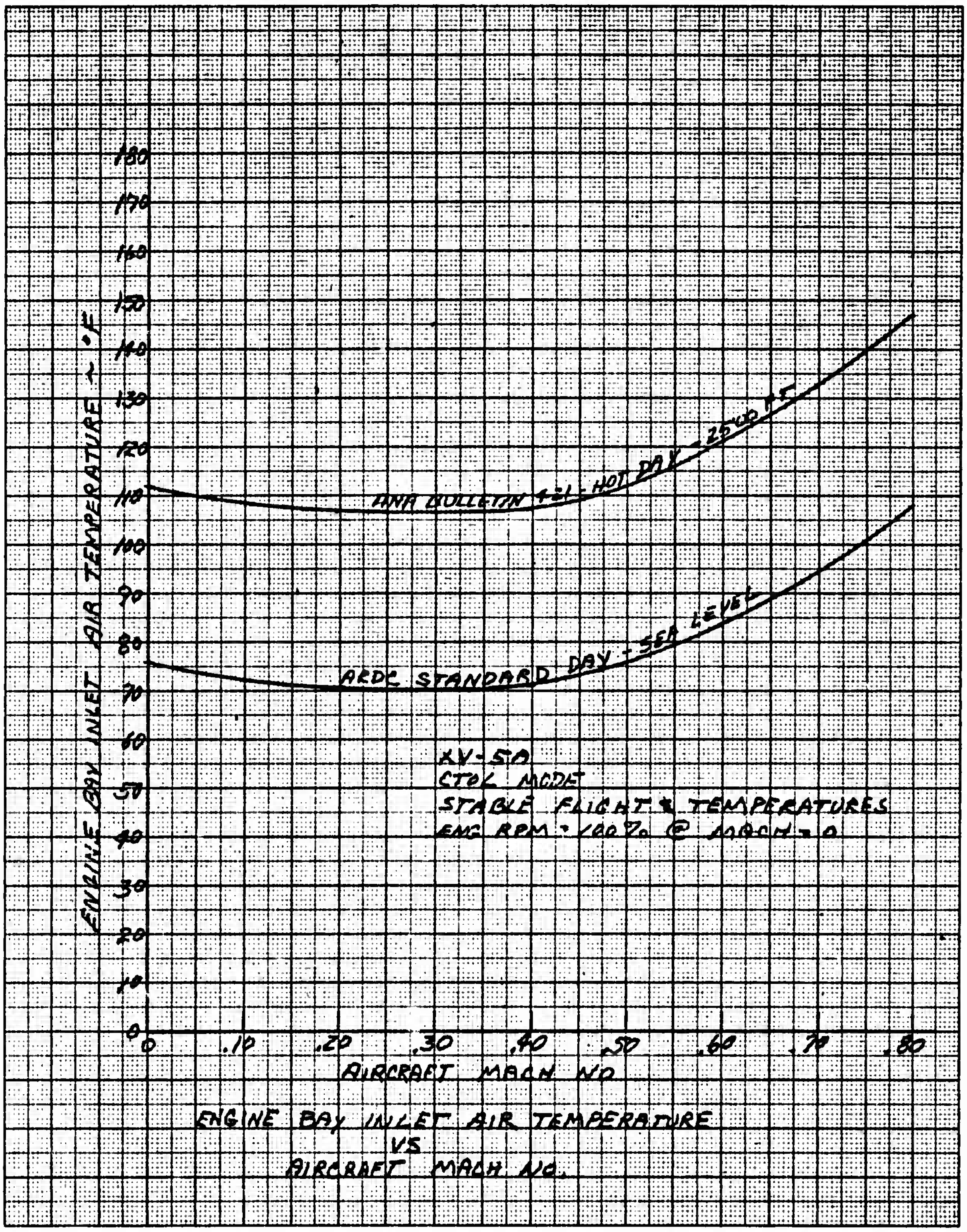

Figure 7.87 **Engine Bay Inlet Air Temperature Vs Aircraft Mach No. - Conventional Steady Flight, Standard Day Sea Level, and Hot Day 2,500 Ft.**

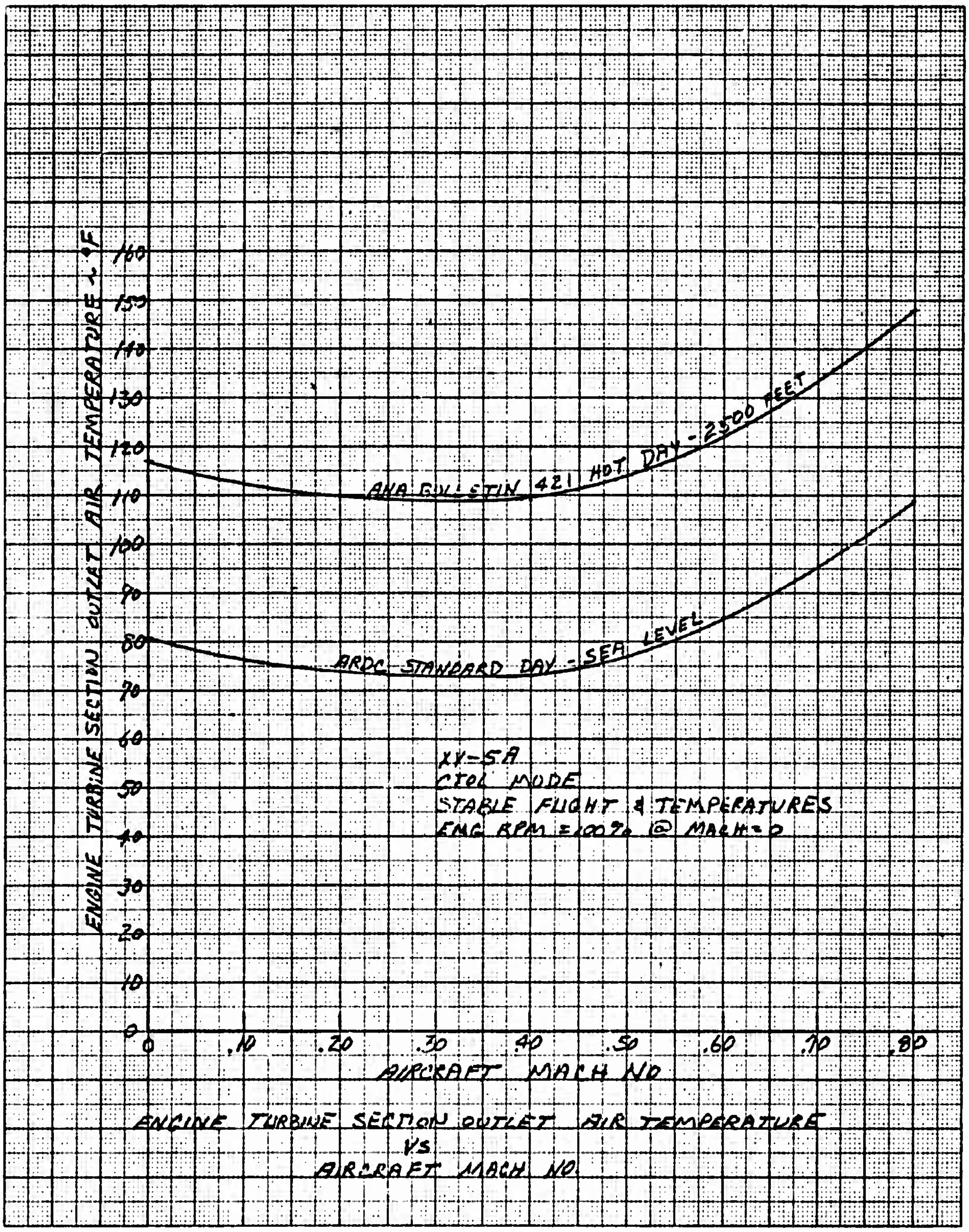

Figure 7.88 Engine Turbine Section Outlet Air Temperature Vs Aircraft Mach No. - Conventional Steady Flight, Standard Day Sea Level, and Hot Day 2,500 Ft.

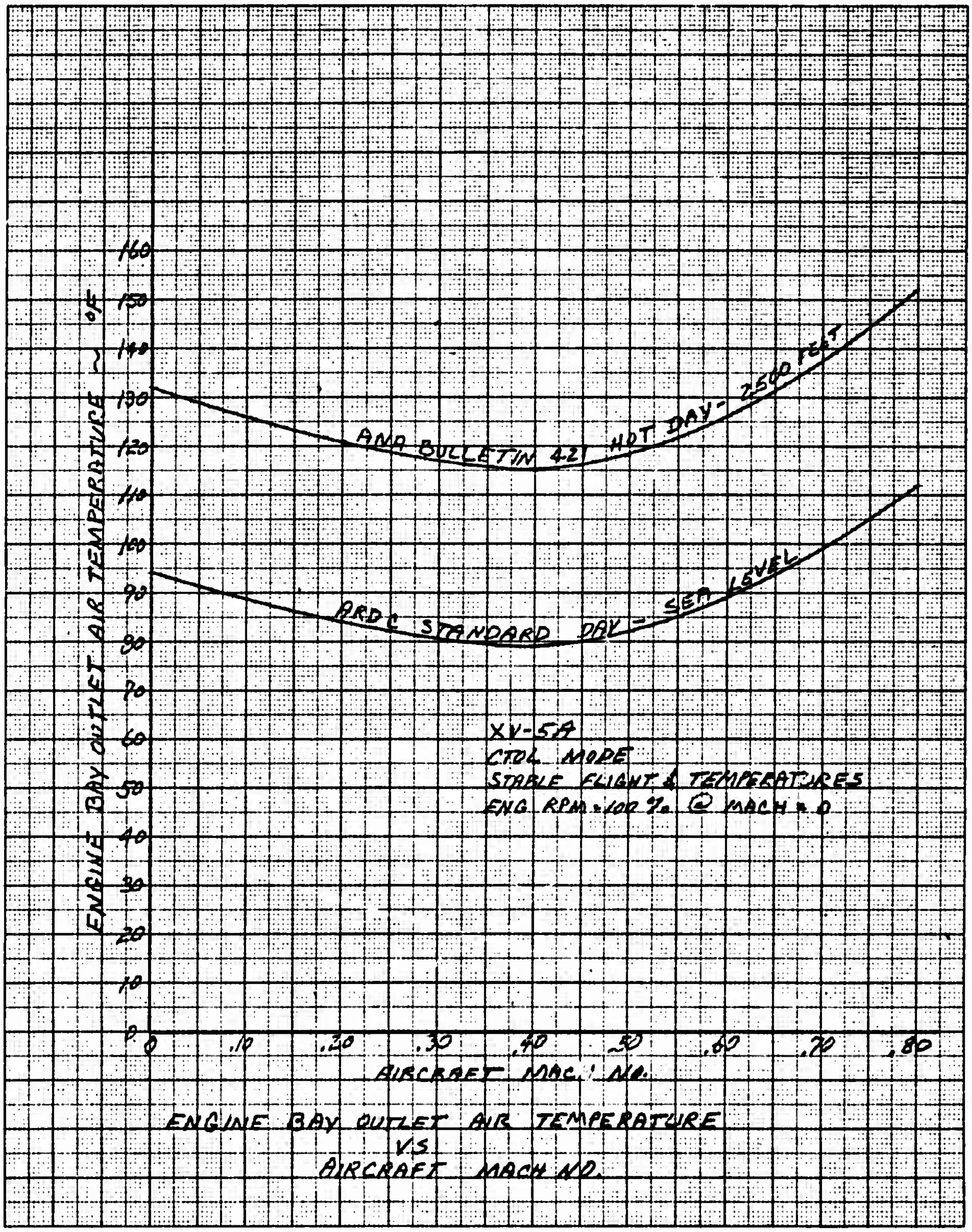

Figure 7.89 Engine Bay Outlet Air Temperature Vs Aircraft Mach No. - Conventional Steady Flight, Standard Day Sea Level and Hot Day 2,500 Ft.

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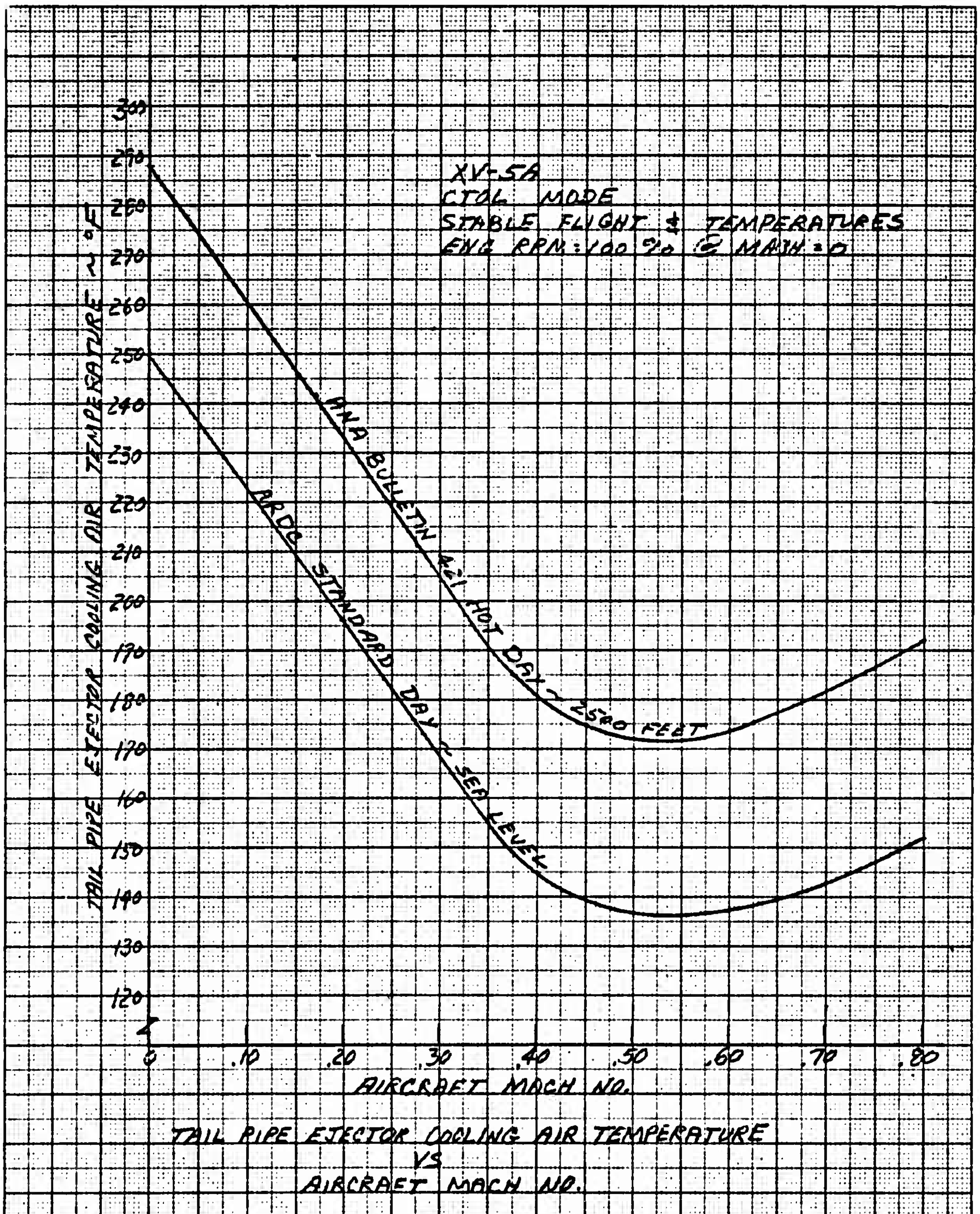

Figure 7.90 Tailpipe Ejector Cooling Air Temperature Vs Aircraft Mach No. - Conventional Steady Flight, Standard Day Sea Level, and Hot Day 2,500 Ft.

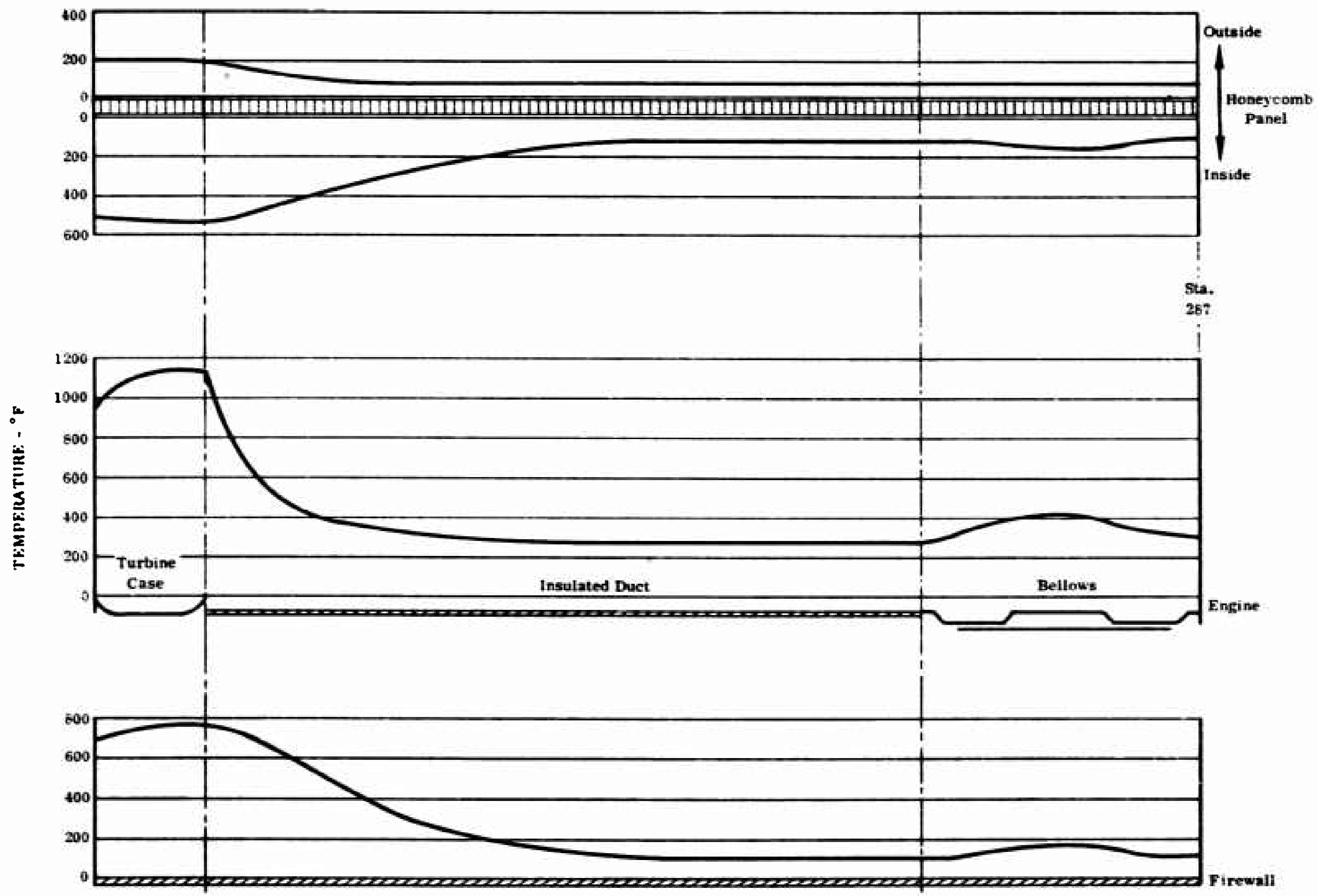

Figure 7.91 Temperature Analysis of Engine Bay - Conventional Mode, Standard Day, Sea Level, 100% RPM

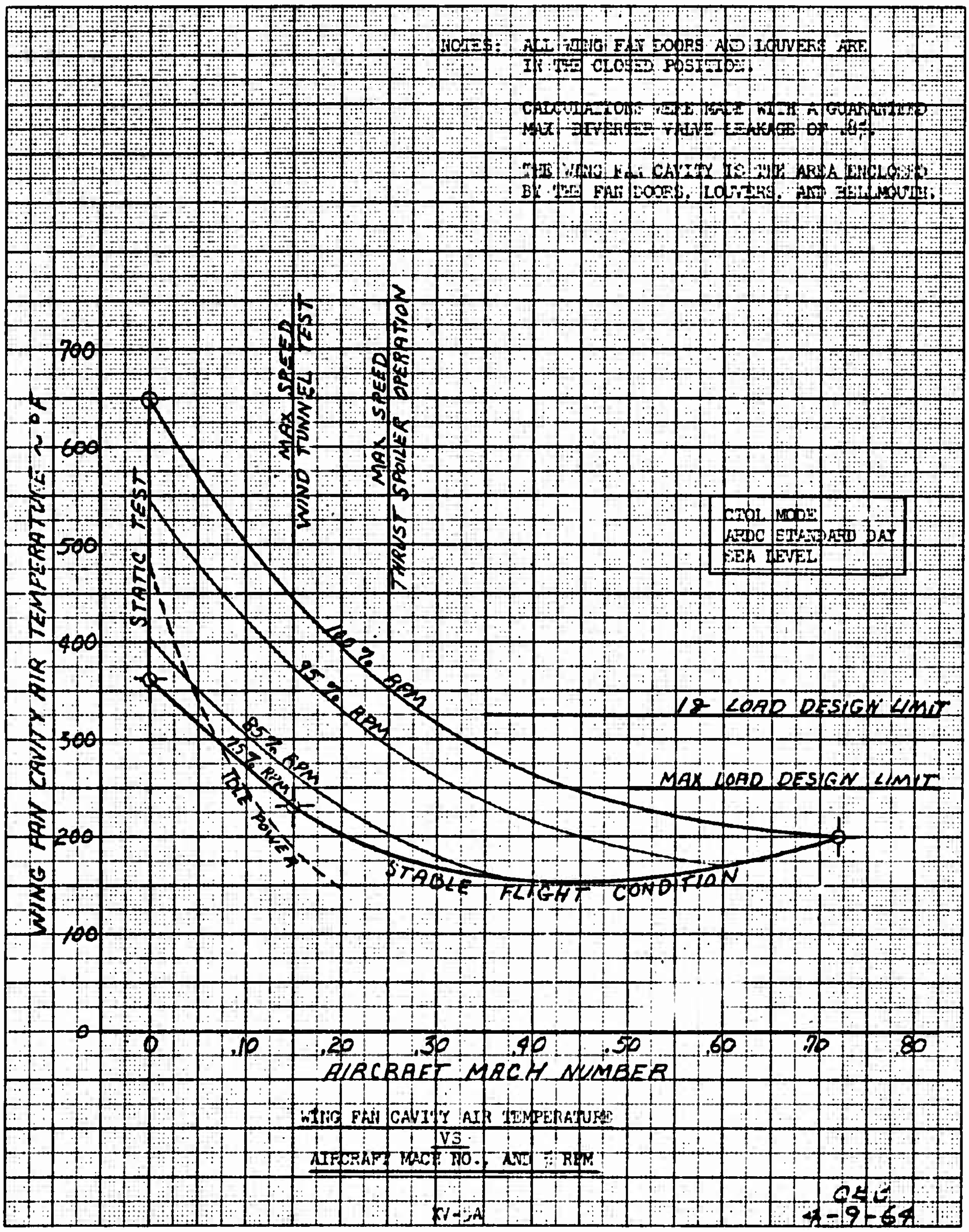

Figure 7.92 Wing Fan Cavity Air Temperature Vs Aircraft Mach and % RPM - Conventional Mode, Standard Day, Sea Level

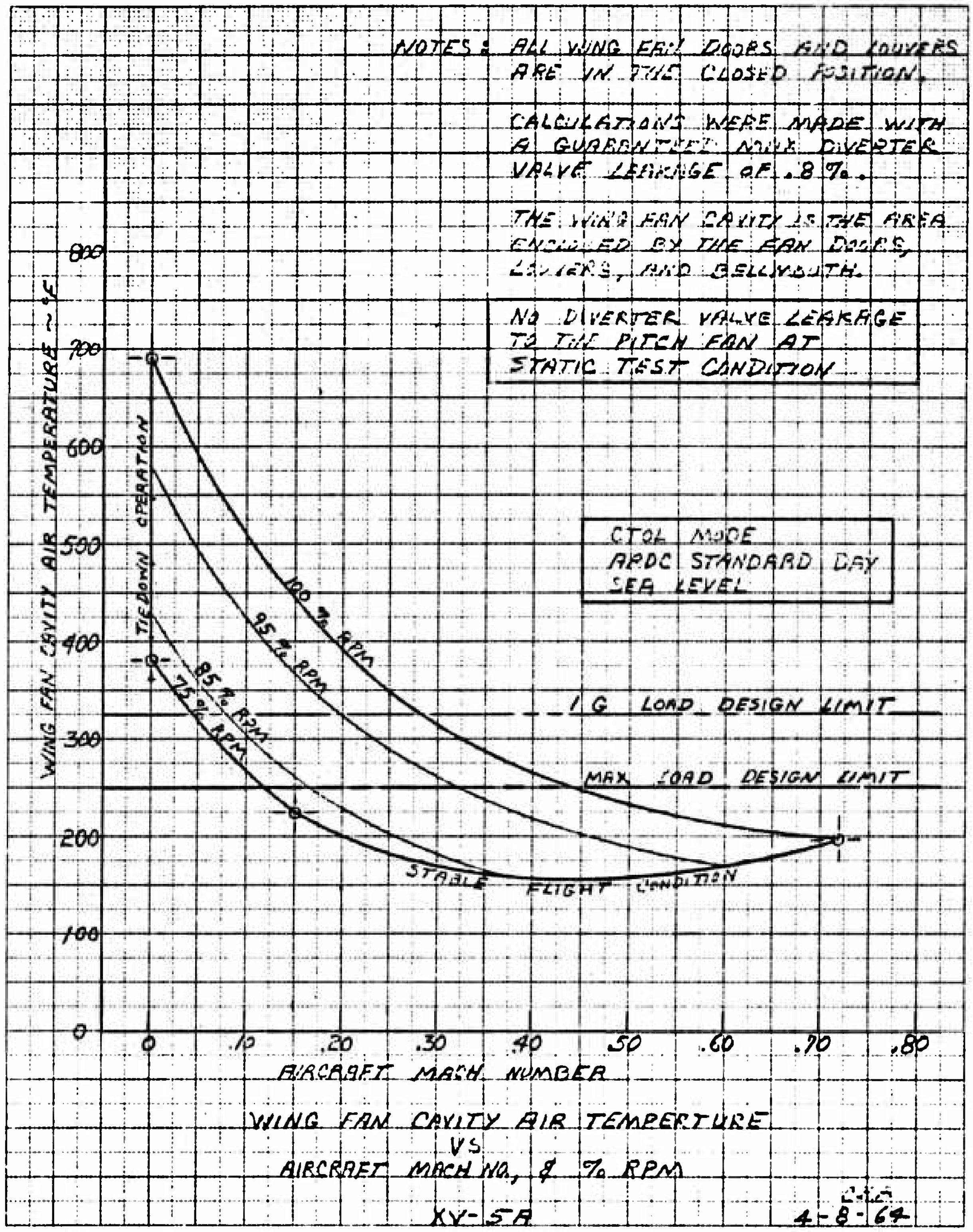

Figure 7.93 Wing Fan Cavity Air Temperature Vs Aircraft Mach and % RPM - Conventional Mode, Standard Day, Sea Level, No Leakage to Nose Fan

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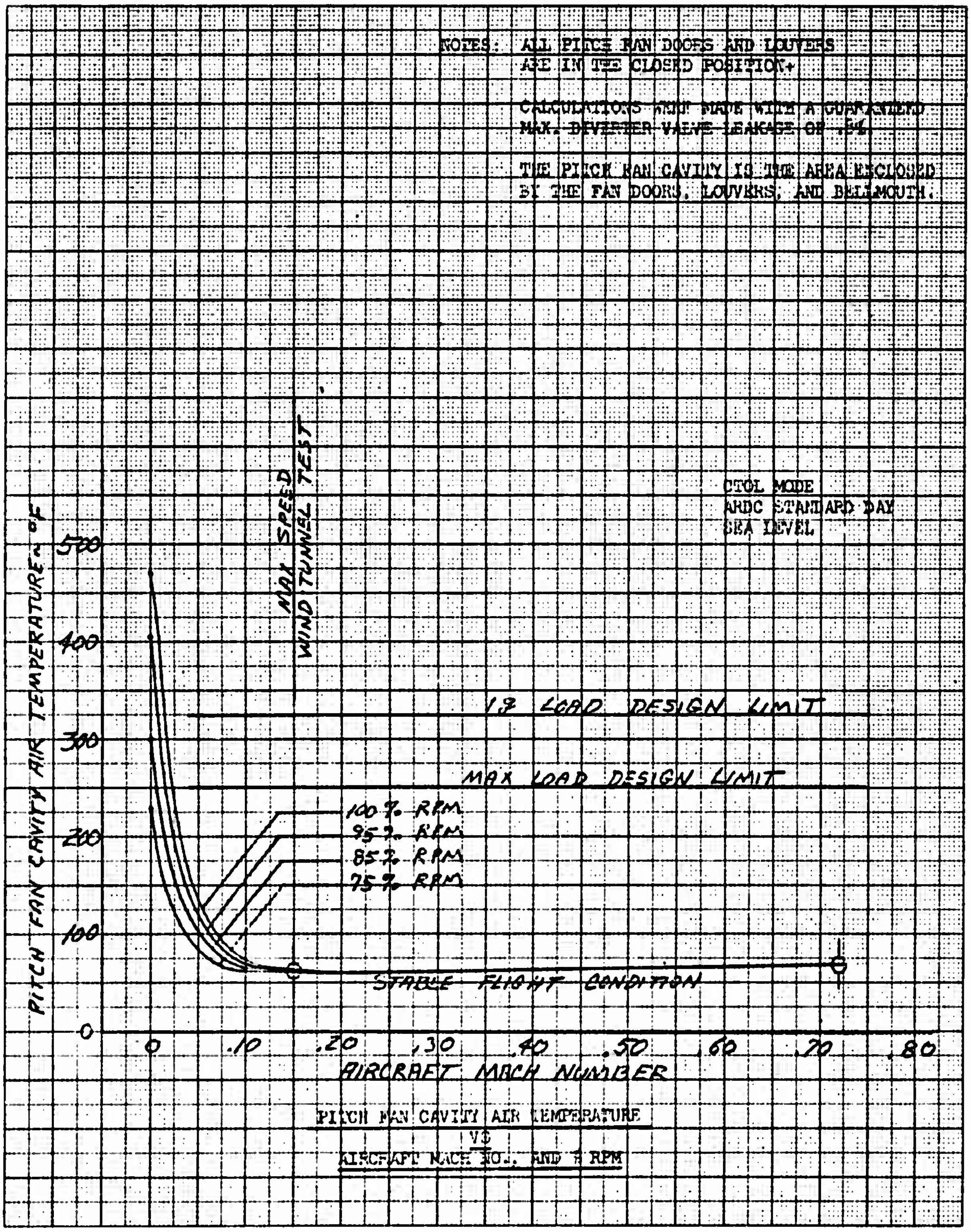

Figure 7.94 Nose Fan Cavity Air Temperature Vs Aircraft Mach and % RPM - Conventional Mode, Standard Day, Sea Level

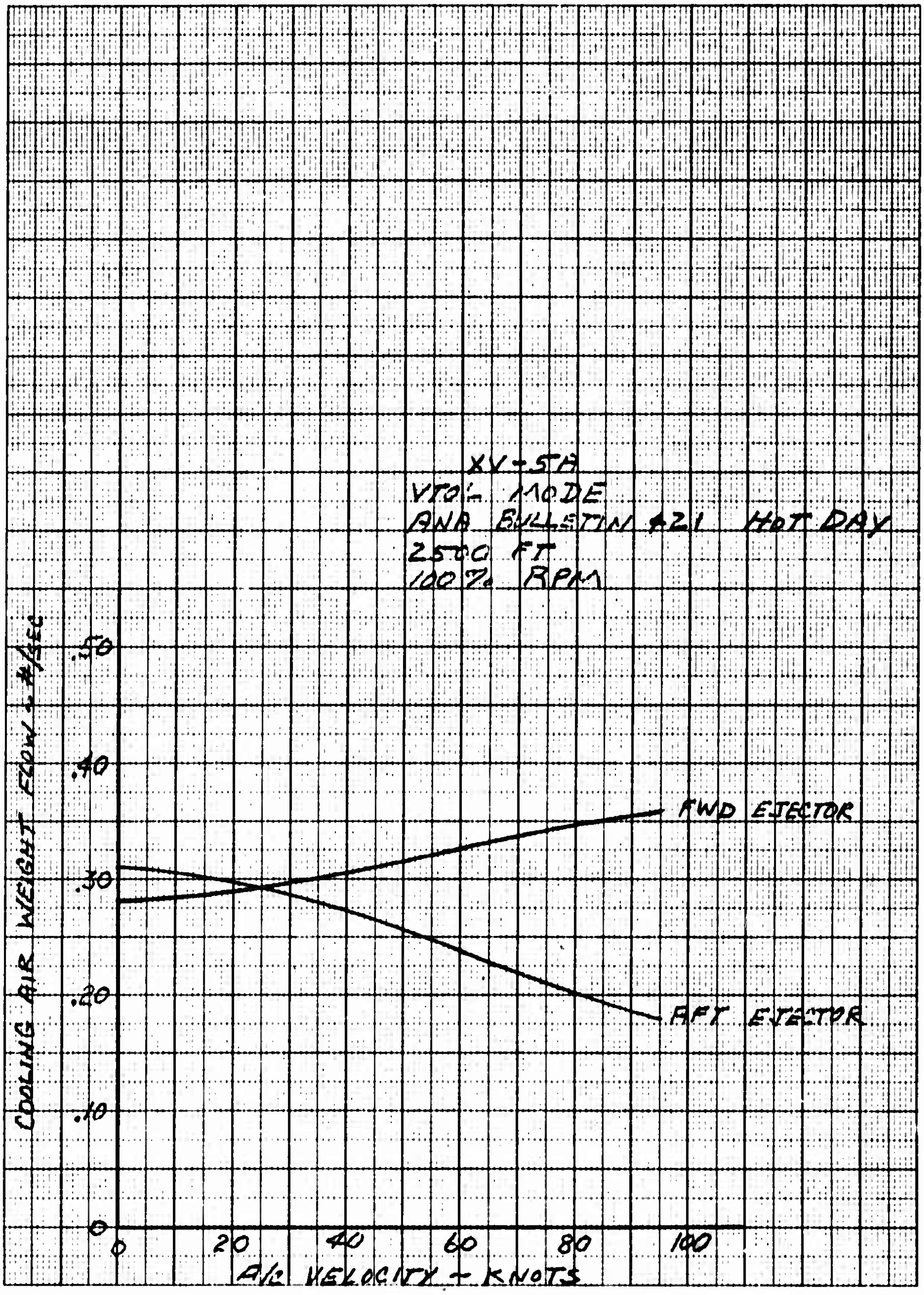

Figure 7.95 Cooling Air Flow - Center Fuselage to Wing Fan Ejectors Vs Aircraft Velocity - Fan Mode, 100% RPM, Hot Day 2,500 Ft.

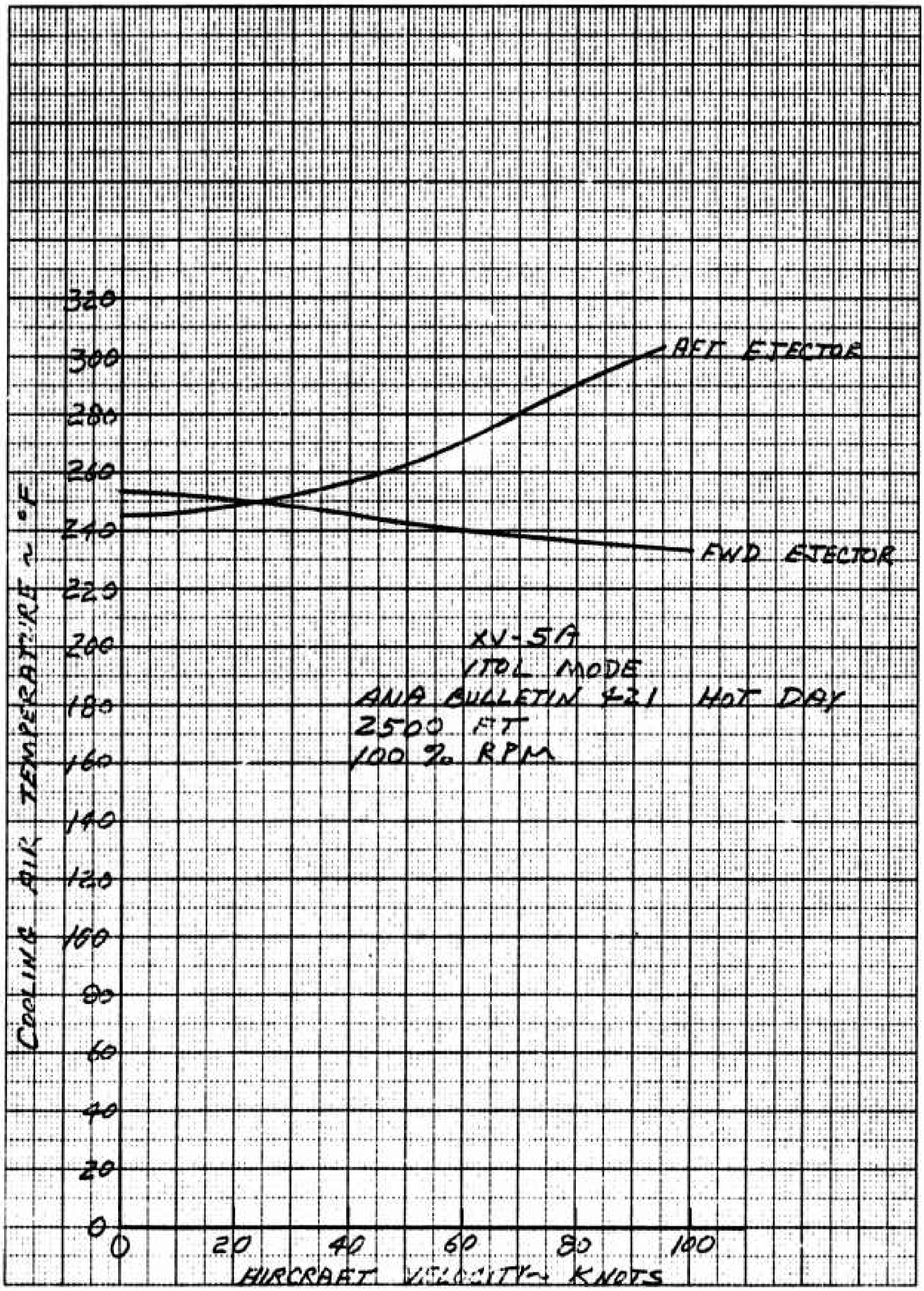

Figure 7.96 Wing Fan Ejector Air Temperature Vs Aircraft Velocity - Fan Mode, 100% RPM, Hot Day 2,500 Ft.

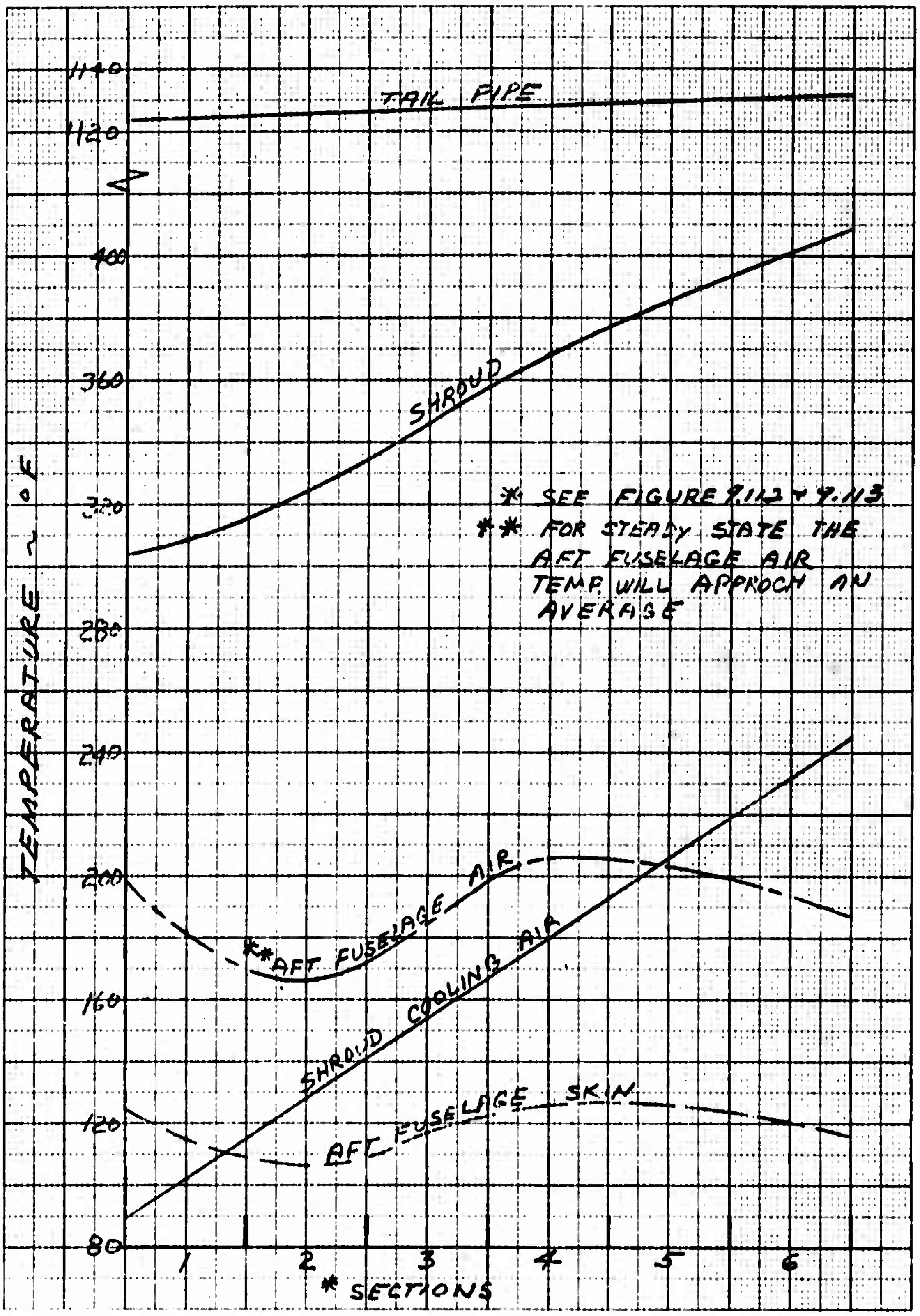

Figure 7.97 Aft Fuselage Air and Structure Temperatures - Conventional Mode, Standard Day Sea Level, 100% RPM

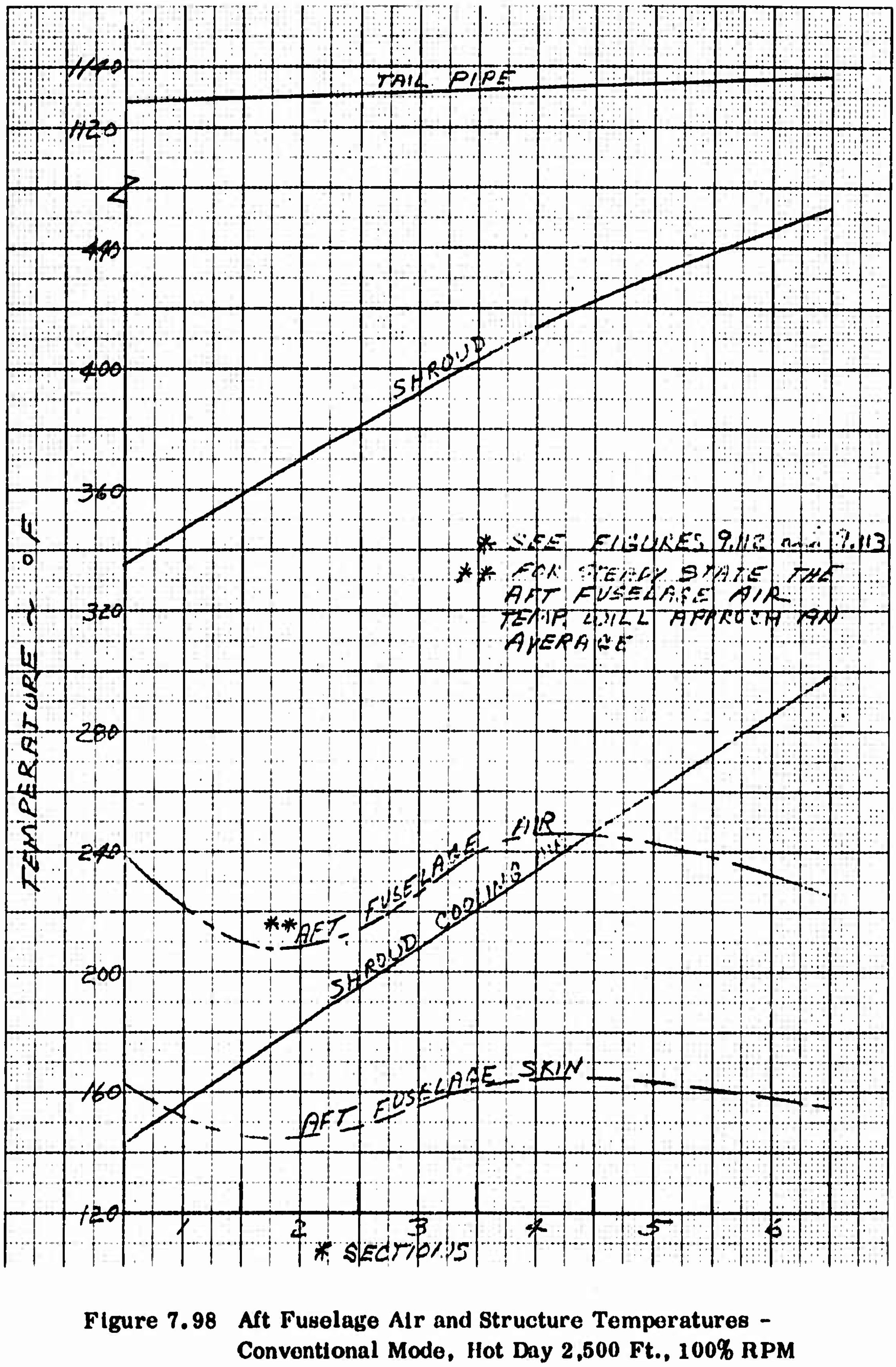

Figure 7.98 Aft Fuselage Air and Structure Temperatures - Conventional Mode, Hot Day 2,500 Ft., 100% RPM

8.0 CONCLUSIONS AND RECOMMENDATIONS

1. The XV-5A aircraft cooling and structural protection systems are estimated to have sufficient performance capability so that the Installed System Functional, NASA-Ames 40' x 80' Wind Tunnel, and the Edwards Air Force Base Flight Test Programs can be conducted in an orderly manner.

2. During turbojet mode operation the following problems may develop:

   a. Reverse flow of hot gases into the aft fuselage and back pressuring of tailpipe may limit thrust spoiler operation and/or require some structural modifications to seal the fuselage-thrust spoiler region.

   b. Cockpit and electronic equipment compartment temperatures may become excessive or exceed allowable limits for prolonged flight at speeds above Mach 0.6 on a hot day at Edwards Air Force Base ground level (2500 feet).

3. During fan mode operation the following problems may develop or are expected:

   a. Main landing gear temperature limits will be exceeded during prolonged operation unless insulated or retracted.

   b. The main landing gear wheel well probably will exceed allowable temperature limits during out of ground effect flight speeds above 30-50 knots unless the doors are closed.

   c. The main landing gear enclosure door magnesium will exceed allowable operating temperatures during fan mode flight at speeds greater than 30 to 50 knots unless insulated, or a material change is made.

   d. The forward tips of the inboard aluminum wing ribs at BL 25 may exceed the allowable operating limit during prolonged operation at aircraft speeds from 80 to 100 knots, however,

it is believed sufficient contact resistance exists which, when combined with the high thermal conductivity of aluminum, will provide satisfactory performance.

e. Hot gas ingestion by the engine and cooling system air inlets during operation in ground effect may have adverse effects on engine performance. For prolonged operation, ingestion may cause excessive temperatures in the cockpit and electronics compartment. No satisfactory method exists for analytically estimating the increase of inlet air temperature due to such ingestion, but full scale model test data from NASA-Ames Test 177 show engine inlet air temperature increases of 100° F are possible. If these levels develop for the cooling air system inlets, relocation of inlets will be required or operational procedures must be modified.

f. Powered fan model data indicate local fuselage surface pressures can promote external hot gas leakage into the center fuselage section. If such leakage develops, more adequate seals should be provided.

4. Existing data in the literature on downwash phenomena may be applied to the XV-5A aircraft to obtain some preliminary qualitative and quantitative estimates of local flow field velocities (or dynamic pressures) and the environment immediately surrounding the aircraft. While more fundamental and experimental data are needed (particularly for vectored fan streams) before important aspects of the flow field can be investigated, evaluations conducted to date show trends and tendencies toward hot gas ingestion, and also point to ways whereby adverse effects may be minimized.

5. The following maximum environmental temperatures are estimated:

a. Titanium canoe section beneath wing fans, 1040° F

b. Lower inboard wing panels between Stations 240 and 280, 1000° F

c. Leading edge of main landing gear wheel well, 860° F

d. Fuselage at wing trailing edge and flap, 850° F for upward flow through flap gap, 250° F for reverse downward flow through flap gap. (The former was used for establishing insulation requirements.)

e. Aft fuselage near thrust spoiler; steel and titanium area, 1250° F, and aluminum area, 550° F

f. Main landing gear, 850° F

g. Nose wheel landing gear, 350° F

h. Under fuselage, 350° F

Adequate structural protection has been provided or can be provided easily for these extremes.

6. During prolonged ground runup or low speed testing in turbojet mode, the fan outlet closures should be open to allow escape of diverter valve leakage, otherwise, fan component temperatures may exceed allowable limits.

7. While cooling system performance capacity appears adequate for all operational requirements, care must be taken to maintain hot gas leakage from the power distribution system within specification limits, otherwise general or local overheating can easily occur.

8. It is recommended that a comprehensive survey be made of the XV-5A induced environment including flow field measurements of temperature and velocity for the full range of aircraft operating conditions such as altitude, power setting, control settings, and local wind velocities.